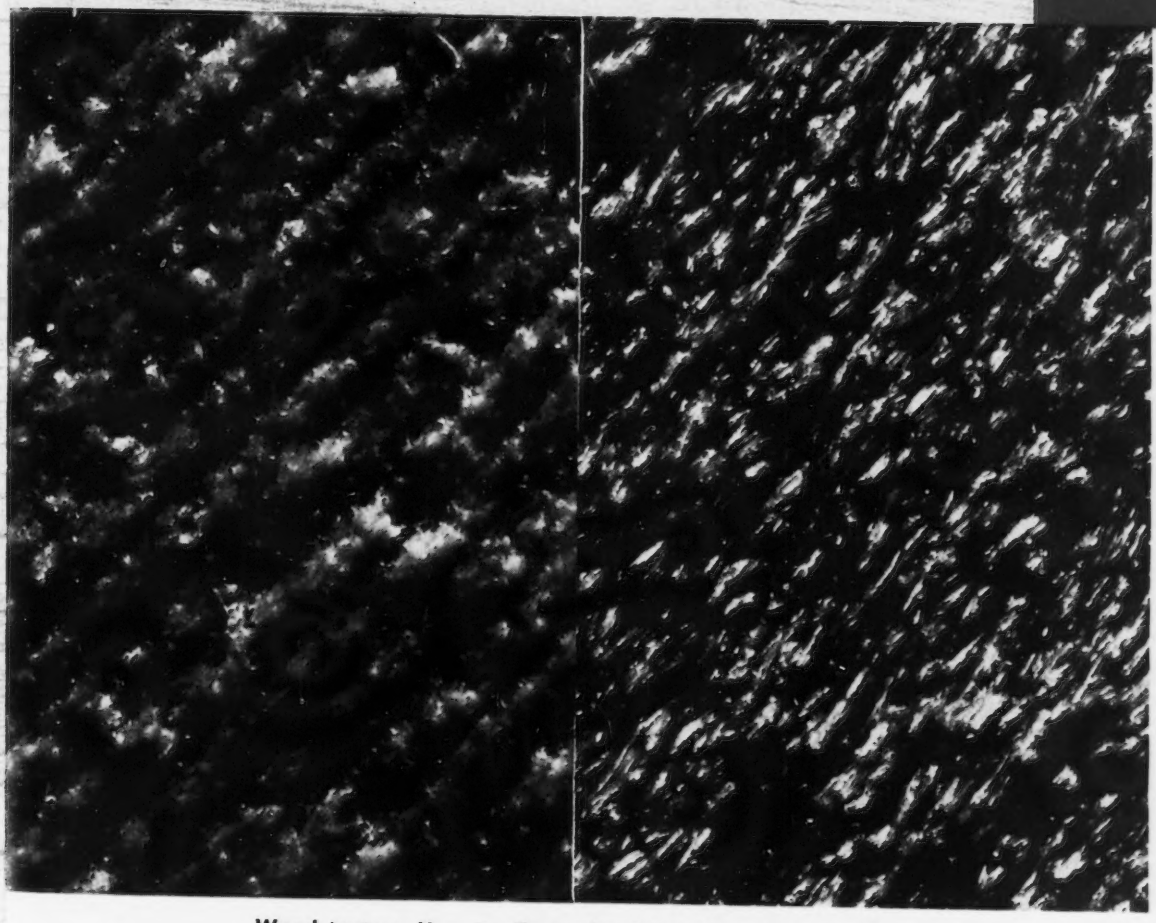
# FOREST PRODUCTS JOURNAL

FOREST PRODUCTS RESEARCH SOCIETY



Wood texture: How it affects glue joint strength. Page 379.

Vol. X, No. 11 1960/NOVEMBER

# BUSS

No. 44 Single Surfacer—4 roll
No. 66 Single Surfacer—6 roll

## THE COMPLETE PLANER LINE

with profit-producing advantages

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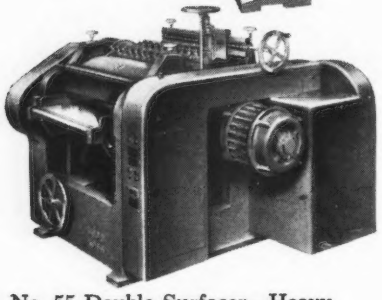

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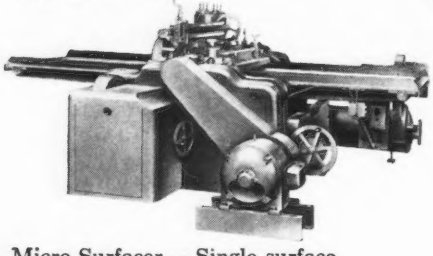

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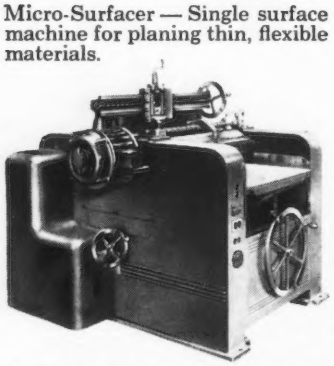

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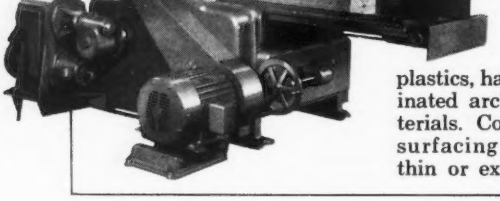
### BUSS SPECIALIZED PRODUCTION SURFACING EQUIPMENT



Top Head Single Planer with chain drag hopper feed to four power rolls.

Buss has designed planers for rubber, vinyl, phenolic, acetate, plastics, hardboard, brake lining, laminated arches, and many other materials. Contact us about any special surfacing problems involving very thin or extremely thick materials.

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# FOREST PRODUCTS JOURNAL

Vol. X, No. 11 November, 1960

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*NO TIME OF YEAR FOR TB. Is there ever a right time? Of course not. But Christmas, more than any other season, should be a time of glowing good spirits, health and happiness. In the fight against TB, it can at least be a time of hope—when millions of healthy Americans take an extra moment to help with each Christmas Seal they use. ✝ Give that spark of hope —and the needed help—by using Christmas Seals. What could be more fitting for a season of good will to men? ✝ Answer your Christmas Seal letter today.* ✝

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# The day that two million pine seedlings grew up

**Two million pine seedlings.**

They were planted a decade ago in Masonite forests. Last year they matured.

Today you'll find them in use as Masonite hardboard.

You'll find them in homes as walls, ceilings, doors, siding, cabinets, shutters, partitions, underlayment, valances, radio and TV sets, bookcases, tables, desks, dressers, magazine racks, play pens, and even children's wading pools.

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# BERNHARDT FURNITURE
## Eliminates Culled Panels with
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"Thanks to Reichhold's PLYAMINE Resin, we have completely eliminated the serious and expensive problem of defective, or 'culled' laminated wood panels caused by resin 'bleed-through'": Colon Prestwood, Plant Superintendent, Bernhardt Furniture Company, Lenoir, N. C.

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## RESIN BLEED-THROUGH NO LONGER A PROBLEM!

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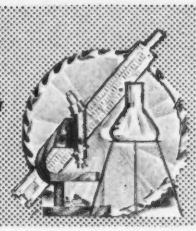
# FPRS News-Digest



# A Message from the President

. . . **Raymond H. Berry**

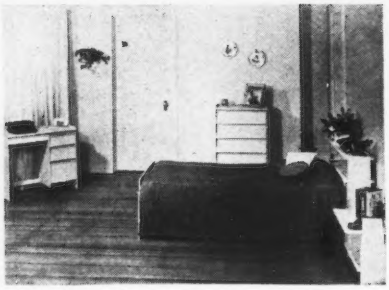
WE ARE LIVING IN A FAST-MOVING, RAPIDLY CHANGING world. What seems important to us today in business, in politics, in education, in religion and in wood technology has a very different feeling, approach and accent from what was experienced as we lived our individual lives 10 years ago, and there was a great change then from what each individual felt in his experience of the world he lived in 10 years before that. Our world today is a totally different world from the one that existed at the turn of the century. Yet I can remember in my boyhood how we felt that we had arrived at almost the acme of progress, with the telephone and electric lights and the development of the railroads, and we looked with somewhat condescending admiration at the primitive hardships of those who lived in the early days of our country.

The change in importance of things in life about us and in the meaning of life from one point in time to another is what creates great difficulty in a proper understanding of the unfolding of history, and has given rise to the oft-raised question of whether history is a science or an art. Change has meaning for us in the Forest Products Research Society. Young as it is, our Society has found in its brief existence since its foundation in 1947, that the changes in the world within the time of its existence have made it necessary to make a survey of its activities and see that its purposes and operations keep step with the changing times. To that end, a Policy Committee was appointed in the early part of 1960, which met in April of this year and framed a report which was adopted and approved at the Montreal meeting in June.

A copy of this report, as revised and adopted by the Executive Board on June 6, 1960, was printed in the October issue of the *Journal* on page 32–A under the title "Official Statement of FPRS Policy." This statement defines and classifies the membership interests, and it reaffirms the purposes for which the Society exists. It outlines objectives and means for carrying out these purposes for the benefit of all of the interested groups within the Society. In essence, it states that the overall objective of the Society—which will be achieved through meetings, the publication of the *Journal*, and the services of the National Office—is to furnish a continuum that will weld together the diverse interests of all whose lives and businesses touch upon the wood industry.

The Committee was appointed and its work has been completed. However, the problems raised in policy for the Society are not static. In a dynamic world where there is continuous and continual change, there must be constant adjustment. What has been done by the Policy Committee is only a beginning. There are many interpretations that have to be made and many gaps that have to be filled, such as in connection with the management of the *Journal*, the functioning of the committees and officers, and the services of the National Office. It is for this reason that I would like to see the establishment of a permanent Policy Committee to keep matters of policy current.

Perhaps we can here find some use for our now disregarded Past Presidents, whose wealth of experience in the affairs of the Society is not now being utilized.



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The five-day course is described as the only one of its kind for wholesalers, commission men, retailers, salesmen, inspectors, graders, building contractors, architects, etc. It is sponsored by the Department of Forest Products and the Cooperative Extension Service of Michigan State University, with the cooperation of The California Redwood Association, the Northern Hardwood and Pine Manufacturers Association, the Southern Pine Inspection Bureau, the West Coast Lumber Inspection Bureau, and the Western Pine Association.

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## Lawyers Form Committee on Timber Resources

The increasing importance of forests, tree farming and multiple use of forest lands in the American economy was influential in the establishment of the Committee on Timber and Vegetative Resources in the American Bar Association's Section of Mineral and Natural Resources Law at the recent Annual Meeting of the ABA in Washington, D. C.

L. Clair Nelson, Associate Counsel of The Champion Paper and Fibre Company, Hamilton, Ohio, is Chairman of the new Committee.

In reviewing the job ahead for this Committee, Mr. Nelson stated that one of the principal objectives would be to obtain recognition within the ABA of the problems involving timber, tree farming and forest lands, and by that means to utilize the force of the ABA to advance proper recognition of the modern concept of timber as a replenishable natural resource. Also, he stated it is hoped that the Committee may serve as a clearing house for legal information in this specialized but rapidly growing field.

## IWRS Meets At Seattle

A second and informal meeting of the new International Wood Research Society (IWRS) was held in Seattle, Wash., on September 7 in conjunction with the Fifth World Forestry Congress. Dr. L. J. Markwardt, former Assistant Director of the U. S. Forest Products Laboratory, and a Vice President of the new Society, acted as chairman.

The main purpose of the meeting was to acquaint interested members of the Congress with the purposes and functions of the Society, which held its first meeting in Paris last May (See August *World Wide News* page 428.)

In addition to Dr. Markwardt, speakers included Dr. E. Glesinger, Director of FAO's Forestry and Forest Products Division and IWRS Executive Secretary, and Monsieur Y. Marcon, Director of the Centre Technique de Bois, Paris.

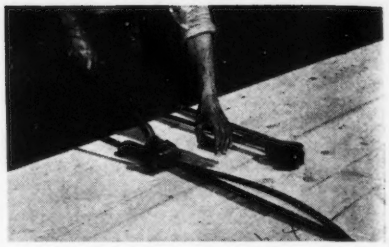
Professor R. W. Wellwood, University of British Columbia, and International Editor of the *Forest Products Journal,* was also in attendance.

## Forest Service Lab Dedicated at Gulfport

Dedication of the new $350.000 U. S. Forest Service Laboratory in Gulfport took place Oct. 16 with U.S. Senator John C. Stennis (D-Miss) delivering the dedicatory address in front of the modern two-story brick building at 34th St. and 24th Ave.

Philip A. Briegleb of New Orleans, director of Southern Forest Experimental Station was master of ceremonies.

The new research installation provides 19,000 square feet of floor space for the modern laboratory and office facilities for three field units of the Southern Forest Experiment Station. They are the Southern Institute of Forest Genetics, headed by Dr. B. W. Henry; the Forest Insect Laboratory, directed by Harmon R. Johnston and the Forest Disease Laboratory under the direction of Dr. A. F. Verrall of New Orleans.



## New Signode Tensioners

Two new strapping tensioners, the TH34 and TH114, have been released by the Signode Steel Strapping company, Chicago, after completion of laboratory- and field-testing programs. They apply the principle of the self-energized feed wheel to manual heavy-duty strapping operations. High speed strap take-up of the TH heavy duty tensioners, teamed with the unlimited take-up of feed wheel tools and the flexibility of manual strapping, make the new models particularly important to lumbermen whose operations doesn't lend itself to stationary or semi-stationary strapping stations.

## Illinois to Study Component Construction

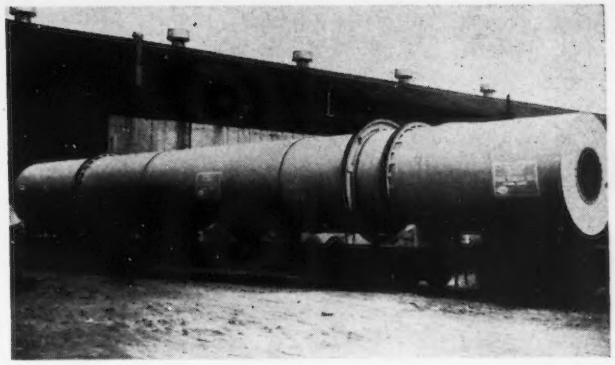
A new research project on the designing and re-evaluation of components for residential construction, will be conducted by the Small Homes Council-Building Research Council of the University of Illinois under sponsorship of the Lumber Dealers Research Council of Washington, D. C.

The work will be carried out under the direction of Rudard A. Jones, research professor of architecture and SHC–BRC director, with Donald H. Percival, research assistant professor of wood technology and utilization, as project supervisor of the component study.

Three separate studies will be incorporated in the component project: 1) the development of a nail-glued roof frame for 1½-story houses; 2) the redesigning of the SHC-BRC four-foot nail-glued header (developed for the wall panel framing system) to adapt it for use for 7′6″ ceilings; and 3) a time-study and re-evaluation of four different types of floor systems for either conventional or component construction.

## Kiln Drying Group Holds Fall Meeting

The Annual Fall Meeting of the New England Kiln Drying Association was held October 21 in conjunction with National Forest Products Week, at the University of New Hampshire, Durham, N. H. Papers presented included "The Importance of Proper Seasoning in Merchandising of Northeastern Hardwoods," by Bernie Elliott, Cavanaugh Lumber Co., Manchester, N. H.; "What Proper Seasoning Means in Eastern White Pine Merchandising," by Peter Koch, Champlin Lumber Co., Rochester, N. H.; "Problems in Predrying (Forced Air Drying)" by Richard C. Anderson, Mohawk Wood Products Inc., Broadalbin, N. Y.; and "The Importance of Quality Primary Processing in the Volume Hardwood Market," by Norman Jurkscheit, Reisen-Seidel Hardwood Co., Union, N. J.



## Johnson Reports on Japan at HPI Meeting

The 19th Annual Fall Meeting of the Hardwood Plywood Institute was held October 6th and 7th, at the Dinkler Plaza Hotel in Atlanta, Georgia. Carl D. Wheeler, Georgia Pacific Corporation and president of the Institute, presided at the meeting. Attending were over 90 hardwood producers and their wives from all over the United States, as well as three Canadian and one Panamanian hardwood plywood manufacturers.

Above, Robert J. Weber, (left), Weber Veneer & Plywood Company, Shawano, Wisconsin, and vice president of the Institute, presided at the afternoon session. E. Sigurd Johnson, (right), North Carolina State College, Raleigh, N. C., addressed the convention regarding his observations made this summer of the Japanese hardwood plywood industry.

## Borden Announces New Wood Adhesives

Development by The Borden Chemical Company of four new polyvinyl acetate wood adhesives for building, furniture, and assembly applications has been announced by R. J. Lodge, general manager, Resins & Chemicals Department.

The new adhesives will be marketed under Borden's "Cascorez" trade name. The products are designed specifically for assembly of pre-fabricated cabinets, built-in furniture units, stair units, general and on-site millwork, custom panelling and partitions, pre-fabricated closet and door assemblies in the building field. Manufacturing applications include flush doors, furniture assembly, laminations and overlaying of veneers, high density plastics, furniture panels, core panels, hardboards, and construction of office, industrial and home partitions.

## Components Discussed at BRI Meeting

The Building Research Institute's semi-annual research correlation conference was held this fall, November 15–17, in Washington D. C. at the Shoreham Hotel. Subjects discussed at the meeting were pre-assembled components, fasteners for industrial curtain walls, structural foams, and new building research.

## Lumber Seasoning Course Announced

A six-day course in lumber seasoning will be offered at the Oregon Forest Research Center, in Corvallis, this fall, according to L. D. Espenas, Director of Forest Products Research. The course will be held in Corvallis, Oregon, from November 28 to December 3.

Cooperating with the research center are the Pacific Northwest Forest and Range Experiment Station, Oregon State College School of Forestry, and the U. S. Forest Products Laboratory, Madison, Wisconsin.

The course is aimed primarily for the benefit of kiln operators, but personnel from management, supervisory, and sales staff should find attendance profitable as well as interesting. The instruction will consist of lectures, demonstrations, laboratory exercises, and actual operation of drying equipment.

Enrollment in the course will be limited to 30 persons to provide effective instruction. Application forms and additional information may be obtained by writing to the Oregon Forest Research Center, P. O. Box 571, Corvallis, Oregon.

## California FPL Reviews Wood Pulping Process

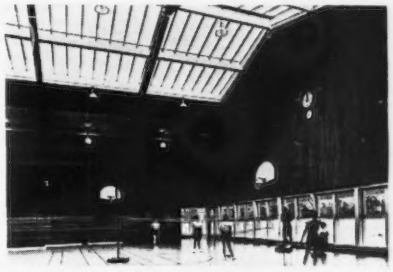
Representatives of 11 California lumber companies met at the University of California's Forest Products Laboratory on the Richmond Field Station October 7, to review progress in the development of a nitric acid wood pulping process that could prove a boon to the state's timber, paper and farming industries.

In company with FPL Director Fred E. Dickinson and Dr. David L. Brink, associate wood chemist who heads the project, they formulated plans for continued work on the process. The firms have made grants-in-aid totalling more than $10,000 to support the research during the current year.

Brink reported recently that the process appears capable of producing many kinds of wood pulps and fertilizers for California's expanding industrial and agricultural markets. It employs nitric acid and ammonium hydroxide in a two-stage operation to make pulps from wood chips, sawdust and other residues, and converts the effluents or wastes into fertilizer.

## New Dryer For Particle Board

This big 9-ft. diameter by 80-ft. long Standard rotary dryer has been delivered to United States Plywood for installation at its new particle board plant in South Boston, Va. Dryer was designed by Standard Steel Corporation, and manufactured at Standard's Leader Iron Works Division in Decatur, Ill. United States Plywood will use the unit to dry wood chips and flakes for use in the manufacture of Novoply, a patented particle board. The dryer was designed to use hot gases from the combustion system of the plant boiler for its heat source, thus eliminating the need for a separate combustion chamber.



## NLMA Shows Wood in Schools

One of the key events of the forthcoming National Retail Lumber Dealers Association exposition in San Francisco will be a dealer clinic to be held daily on "Wood Products Promotion for Profit" with particular emphasis on wood in school construction.

The clinic, sponsored by the National Lumber Manufacturers Association, will feature a panel discussion with 2 prominent school architects, a wood technologist, a lumber dealer experienced in school work and a promotion-merchandising expert. Dealers and convention visitors will also be given the opportunity to see the NLMA's newest full color film on the application of lumber and wood products in school design.

As part of NLMA's continuing program of wood promotion activities, 4 folders have been recently published on "Why Wood is Best For: Flooring, siding, Paneling, and Framing and Sheathing." These colorful new folders are the first in a complete series of informational pamphlets to be developed by the lumber group. Other folders in the series will cover such subjects as doors, windows, furniture, cabinetry, and built-ins.

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In reviewing the job ahead for this Committee, Mr. Nelson stated that one of the principal objectives would be to obtain recognition within the ABA of the problems involving timber, tree farming and forest lands, and by that means to utilize the force of the ABA to advance proper recognition of the modern concept of timber as a replenishable natural resource. Also, he stated it is hoped that the Committee may serve as a clearing house for legal information in this specialized but rapidly growing field.

## IWRS Meets At Seattle

A second and informal meeting of the new International Wood Research Society (IWRS) was held in Seattle, Wash., on September 7 in conjunction with the Fifth World Forestry Congress. Dr. L. J. Markwardt, former Assistant Director of the U. S. Forest Products Laboratory, and a Vice President of the new Society, acted as chairman.

The main purpose of the meeting was to acquaint interested members of the Congress with the purposes and functions of the Society, which held its first meeting in Paris last May (See August *World Wide News* page 428.)

In addition to Dr. Markwardt, speakers included Dr. E. Glesinger, Director of FAO's Forestry and Forest Products Division and IWRS Executive Secretary, and Monsieur Y. Marcon, Director of the Centre Technique de Bois, Paris.

Professor R. W. Wellwood, University of British Columbia, and International Editor of the *Forest Products Journal,* was also in attendance.

## Forest Service Lab Dedicated at Gulfport

Dedication of the new $350,000 U. S. Forest Service Laboratory in Gulfport took place Oct. 16 with U.S. Senator John C. Stennis (D-Miss) delivering the dedicatory address in front of the modern two-story brick building at 34th St. and 24th Ave.

Philip A. Briegleb of New Orleans, director of Southern Forest Experimental Station was master of ceremonies.

The new research installation provides 19,000 square feet of floor space for the modern laboratory and office facilities for three field units of the Southern Forest Experiment Station. They are the Southern Institute of Forest Genetics, headed by Dr. B. W. Henry; the Forest Insect Laboratory, directed by Harmon R. Johnston and the Forest Disease Laboratory under the direction of Dr. A. F. Verrall of New Orleans.

## New Signode Tensioners

Two new strapping tensioners, the TH34 and TH114, have been released by the Signode Steel Strapping company, Chicago, after completion of laboratory- and field-testing programs. They apply the principle of the self-energized feed wheel to manual heavy-duty strapping operations. High speed strap take-up of the TH heavy duty tensioners, teamed with the unlimited take-up of feed wheel tools and the flexibility of manual strapping, make the new models particularly important to lumbermen whose operations doesn't lend itself to stationary or semi-stationary strapping stations.

## Illinois to Study Component Construction

A new research project on the designing and re-evaluation of components for residential construction, will be conducted by the Small Homes Council-Building Research Council of the University of Illinois under sponsorship of the Lumber Dealers Research Council of Washington, D. C.

The work will be carried out under the direction of Rudard A. Jones, research professor of architecture and SHC–BRC director, with Donald H. Percival, research assistant professor of wood technology and utilization, as project supervisor of the component study.

Three separate studies will be incorporated in the component project: 1) the development of a nail-glued roof frame for 1½-story houses; 2) the redesigning of the SHC-BRC four-foot nail-glued header (developed for the wall panel framing system) to adapt it for use for 7'6" ceilings; and 3) a time-study and re-evaluation of four different types of floor systems for either conventional or component construction.

## Kiln Drying Group Holds Fall Meeting

The Annual Fall Meeting of the New England Kiln Drying Association was held October 21 in conjunction with National Forest Products Week, at the University of New Hampshire, Durham, N. H. Papers presented included "The Importance of Proper Seasoning in Merchandising of Northeastern Hardwoods," by Bernie Elliott, Cavanaugh Lumber Co., Manchester, N. H.; "What Proper Seasoning Means in Eastern White Pine Merchandising," by Peter Koch, Champlin Lumber Co., Rochester, N. H.; "Problems in Predrying (Forced Air Drying)" by Richard C. Anderson, Mohawk Wood Products Inc., Broadalbin, N. Y.; and "The Importance of Quality Primary Processing in the Volume Hardwood Market," by Norman Jurkscheit, Reisen-Seidel Hardwood Co., Union, N. J.

## Johnson Reports on Japan at HPI Meeting

The 19th Annual Fall Meeting of the Hardwood Plywood Institute was held October 6th and 7th, at the Dinkler Plaza Hotel in Atlanta, Georgia. Carl D. Wheeler, Georgia Pacific Corporation and president of the Institute, presided at the meeting. Attending were over 90 hardwood producers and their wives from all over the United States, as well as three Canadian and one Panamanian hardwood plywood manufacturers.

Above, Robert J. Weber, (left), Weber Veneer & Plywood Company, Shawano, Wisconsin, and vice president of the Institute, presided at the afternoon session. E. Sigurd Johnson, (right), North Carolina State College, Raleigh, N. C., addressed the convention regarding his observations made this summer of the Japanese hardwood plywood industry.

## Borden Announces New Wood Adhesives

Development by The Borden Chemical Company of four new polyvinyl acetate wood adhesives for building, furniture, and assembly applications has been announced by R. J. Lodge, general manager, Resins & Chemicals Department.

The new adhesives will be marketed under Borden's "Cascorez" trade name. The products are designed specifically for assembly of pre-fabricated cabinets, built-in furniture units, stair units, general and on-site millwork, custom panelling and partitions, pre-fabricated closet and door assemblies in the building field. Manufacturing applications include flush doors, furniture assembly, laminations and overlaying of veneers, high density plastics, furniture panels, core panels, hardboards, and construction of office, industrial and home partitions.

## Components Discussed at BRI Meeting

The Building Research Institute's semi-annual research correlation conference was held this fall, November 15–17, in Washington D. C. at the Shoreham Hotel. Subjects discussed at the meeting were pre-assembled components, fasteners for industrial curtain walls, structural foams, and new building research.

## Lumber Seasoning Course Announced

A six-day course in lumber seasoning will be offered at the Oregon Forest Research Center, in Corvallis, this fall, according to L. D. Espenas, Director of Forest Products Research. The course will be held in Corvallis, Oregon, from November 28 to December 3.

Cooperating with the research center are the Pacific Northwest Forest and Range Experiment Station, Oregon State College School of Forestry, and the U. S. Forest Products Laboratory, Madison, Wisconsin.

The course is aimed primarily for the benefit of kiln operators, but personnel from management, supervisory, and sales staff should find attendance profitable as well as interesting. The instruction will consist of lectures, demonstrations, laboratory exercises, and actual operation of drying equipment.

Enrollment in the course will be limited to 30 persons to provide effective instruction. Application forms and additional information may be obtained by writing to the Oregon Forest Research Center, P. O. Box 571, Corvallis, Oregon.

## California FPL Reviews Wood Pulping Process

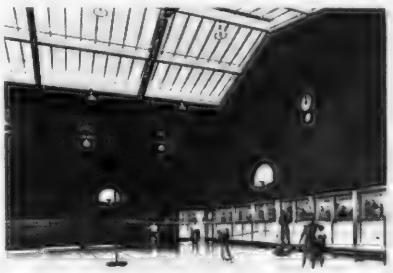
Representatives of 11 California lumber companies met at the University of California's Forest Products Laboratory on the Richmond Field Station October 7, to review progress in the development of a nitric acid wood pulping process that could prove a boon to the state's timber, paper and farming industries.

In company with FPL Director Fred E. Dickinson and Dr. David L. Brink, associate wood chemist who heads the project, they formulated plans for continued work on the process. The firms have made grants-in-aid totalling more than $10,000 to support the research during the current year.

Brink reported recently that the process appears capable of producing many kinds of wood pulps and fertilizers for California's expanding industrial and agricultural markets. It employs nitric acid and ammonium hydroxide in a two-stage operation to make pulps from wood chips, sawdust and other residues, and converts the effluents or wastes into fertilizer.

## New Dryer For Particle Board

This big 9-ft. diameter by 80-ft. long Standard rotary dryer has been delivered to United States Plywood for installation at its new particle board plant in South Boston, Va. Dryer was designed by Standard Steel Corporation, and manufactured at Standard's Leader Iron Works Division in Decatur, Ill. United States Plywood will use the unit to dry wood chips and flakes for use in the manufacture of Novoply, a patented particle board. The dryer was designed to use hot gases from the combustion system of the plant boiler for its heat source, thus eliminating the need for a separate combustion chamber.



## NLMA Shows Wood in Schools

One of the key events of the forthcoming National Retail Lumber Dealers Association exposition in San Francisco will be a dealer clinic to be held daily on "Wood Products Promotion for Profit" with particular emphasis on wood in school construction.

The clinic, sponsored by the National Lumber Manufacturers Association, will feature a panel discussion with 2 prominent school architects, a wood technologist, a lumber dealer experienced in school work and a promotion-merchandising expert. Dealers and convention visitors will also be given the opportunity to see the NLMA's newest full color film on the application of lumber and wood products in school design.

As part of NLMA's continuing program of wood promotion activities, 4 folders have been recently published on "Why Wood is Best For: Flooring, siding, Paneling, and Framing and Sheathing." These colorful new folders are the first in a complete series of informational pamphlets to be developed by the lumber group. Other folders in the series will cover such subjects as doors, windows, furniture, cabinetry, and built-ins.

## Tractor Dozer Exhibited

The pulpwood industry of the northeastern United States was introduced recently to the Eimco Model 103, a 100 HP tractor dozer, demonstrated before the annual meeting of the American Pulpwood Association.

The dozer, equipped especially for the logging and woodpulp industry, operated on a tree farm of the International Paper Company here as part of a 2-day technical session of the A.P.A. It carried a Carco F-7 logging winch, heavy duty logging safety canopy and Shasta-type end bits for the hydraulic-controlled 12′ wide angle blade. In the course of the demonstration, witnessed by representatives of 16 major pulp companies, a road site 50 feet wide was driven through virgin forests to a distance of 800 feet in 5½ hours.

## New Spotnails Plant

Spotnails, Inc., Evanston, Illinois, manufacturers of automatically driven long fasteners used in wood working plants and furniture manufacture, announce the opening of an eastern plant, 33 Terminal Avenue, Clark, New Jersey, to manufacture and distribute their line of nails, pins and staples up to two inches long, and their mallet drive and pneumatic Spotnailing machines. This 14,000 square foot plant will also provide a sales and service center for the eastern region. Faster delivery and minimizing freight costs are two of the reasons that Spotnails has opened this new plant, according to Charles Crooks, President.

## Van-Evan Co. Operating

Now in operation is Montana's newest and largest plywood mill, the Van-Evan Co. at Missoula, jointly owned by Vancouver Plywood Co. and Evans Products Co. The modern plant, costing $2,500,000 has an initial capacity for manufacturing 6,000,000 square feet per month, on a ⅜-inch basis, wood provision for 9,000,000 square feet. The plant's main building is 300 by 500 feet, covering about 3½ acres.

## Commercial Standard on Hardwood Flooring

Quality criteria for Laminated Hardwood Block Flooring is covered by a recommended Commercial Standard which has just been circulated to the industry for approval, according to the Commodity Standards Division, Office of Technical Services, Business and Defense Services Administration, U. S. Department of Commerce.

The new standard covers tongued and grooved hardwood plywood blocks in two grades with either unfinished or pre-finished faces. It was requested by the Hardwood Plywood Institute to provide a common basis of understanding for this type of flooring among manufacturers, architects, builders, distributors, and flooring contractors. Other interested organizations cooperated in the preparation of this standard.

Copies of the Recommended Standard, TS–5506, are available without charge, while the supply lasts, from the Commodity Standards Division, U. S. Department of Commerce, Washington 25, D. C. (DUdley 6–1207).

## NLMA Increases Dues for "Wood Promotion"

Six of NLMA's federated associations have taken favorable action on the proposal to increase dues to the National Wood Promotion Program from 10 to 16 cents per thousand feet of lumber manufactured by subscribers.

The dues increase has been given final approval by the American Walnut Manufacturers Association, Maple Flooring Manufacturers Association, Fine Hardwoods Association and National Oak Flooring Manufacturers Association. Directors of the West Coast Lumbermen's Association and Northern Hardwood and Pine Manufacturers Association have voted to recommend acceptance of the increase by their members at an early date.

A new 16-page booklet published by NLMA contains a proposed preliminary budget explainng how the dues increase, voted by the National Wood Promotion Committee in San Francisco in May, might be used in expanding NWPP outlays to a projected $2 million in 1961.

## Georgia-Pacific Buys Pilot Rock Lumber Co.

Georgia-Pacific Pine Mills Co., Inc., a wholly owned subsidiary of Georgia-Pacific Corporation, Portland, Oregon, has purchased the Pilot Rock Lumber Co., Pilot Rock, Oregon. Included in the purchase are approximately 100,000 acres of timber and timberlands, largely Ponderosa Pine, located in Grant, Morrow, Umatilla, and Union Counties, in Eastern Oregon. In addition, the properties include a modern lumber plant and planing mills, dry kilns, and related logging and mill manufacturing equipment with an annual production of approximately 50 million board feet.

The purchase price amounted to approximately $11 and ½ million is payable over varying periods up to 20 years on a self liquidating basis geared to the harvest of the timber.

## Industry Leader Sees Unlimited Future For Wood

Wood has a greater future than any other material known to man, including modern metals and plastics, S. W. Antoville, chairman of United States Plywood Corporation, declared in his speech to an audience of more than 300 assembled in Los Angeles, October 18, to celebrate the President's proclamation of the first National Forest Products Week.

He told his listeners that uses for wood and potential markets for wood products are limited only by the "boundaries of man's imagaination." But he urged the forest products industries to consider "much more research and much more 'sell'" to insure the optimistic outlook he depicted.

"Wood," said Mr. Antoville, "is the only natural resource known to man that is inexhaustible when properly managed. None of the mineral and oil resources of the world, from which most other building materials derive, can be replaced within any pratical period of time."

He pointed out that achievements in commercial forest management had resulted in the annual growth of "25 percent more wood by volume than is being harvested."

While detailing strides in recent years that have led to better utilization of timber, Mr. Antoville indicated that forest products research had only scratched the surface.

"It is not inconceivable," he said, "that genetics research will produce a hybrid, fast growing tree for future generations that will be fire-retardant when harvested and whose strength, color and grain characteristics will be predetermined in the laboratory."

"There is nothing in this world," he pointed out, "that can touch wood in terms of availability as a natural resource—or in terms of its economic and structural potential, not to mention the great future it holds as a source of chemicals and plastics."

Markets for improved wood products lay waiting, Mr. Antoville declared, and referred particularly to the "fabulous" farm building renewal market which he said is estimated at the rate of $720,000,000 a year for the next 20 years. He also pointed to increased housing starts and growth of the furniture industry, both assured by population growth, as reasons for optimism on the part of wood products industries.

## NLMA Replaces U. N. Head's Gavel

Dr. Frederick H. Boland, President of the United Nations General Assembly, has a brand new gavel made of American walnut and maple to replace the one he broke October 12 while restoring order in the General Assembly.

The gavel and pounding block were flown to him by the National Lumber Manufacturers Association from Washington, D. C. October 13 and were presented by John L. Jones, Vice President of Union Lumber Company, of New York City, on behalf of NLMA President, Thomas J. McHugh, Chairman of the Board of the Atlantic Lumber Company.

## FPRS SECTION MEMBERSHIP GOALS

**Wanted: 300 New Members by June 1, 1961**

| SECTION | NEW VOTING & ASSOCIATE MEMBERS | MEMBERSHIP CHAIRMAN |
|---|---|---|
| Midwest | 30 | R. C. Newstedt |
| Ohio Valley | 10 | H. E. Cook |
| Great Lakes | 20 | N. C. Franz |
| Upper Mississippi Valley | 10 | L. A. Ropella |
| Mid-South | 25 | H. L. Russell |
| Northeast | 50 | R. C. Gill |
| Eastern Canadian | 20 | Alfred Glennie |
| Carolinas–Chesapeake | 25 | Sam Freeman |
| Southeastern | 10 | P. J. Bois |
| Pacific Northwest | 50 | Tom McKenna |
| Inland Empire | 10 | R. L. McNett |
| Northern California | 20 | Victor Roth |
| Rocky Mountain | 10 | Robert S. Bader |
| Pacific Southwest | 10 | W. E. Ripley, Jr. |

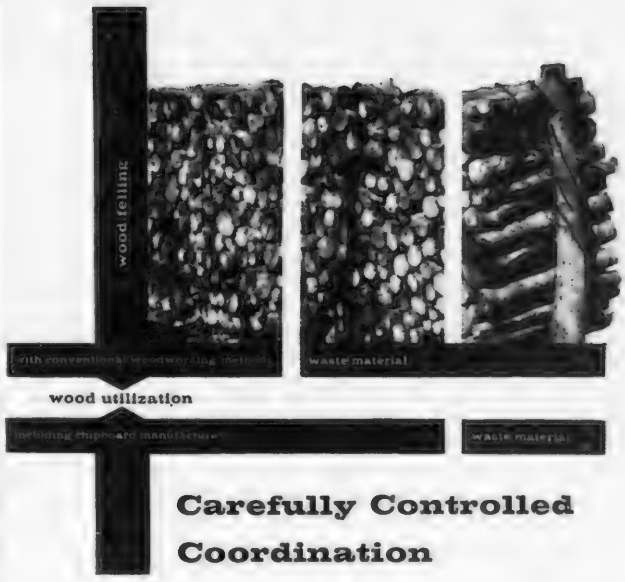
*Help your membership chairman meet his quota!*

INITIAL MEETING OF PULP AND PAPER FOUNDATION to help students through forestry college course, in October—Seated: J. L. Ober, Maine Pulp & Paper Foundation, main speaker at founding dinner; Hardy L. Shirley, Dean N.Y. State College of Forestry; R. F. Vokes, first President of the Foundation; F. W. O'Neil, head of the pulp and paper making course at the College. L. R. Ayers and H. M. Gray. Standing: D. M. Mawhinney, W. H. Kennedy, G. L. Bidwell, C. O. Skoggard, W. B. Morehouse, Larry Byrns, G. S. McCrea, Paul Dunn, George Haines, C. C. Landegger, J. P. Rogers, R. P. Price, John Milliken, M. D. Conklin and E. C. Jahn, Association Dean, College of Forestry.

### Paper Industry Sets Educational Foundation at Syracuse

The leading paper companies of the country have established Syra- se Pulp and Paper Foundation, Inc., to help gifted science students, ho choose the paper industry for a career, to obtain their pulp and per making education at the New York State college of forestry at racuse University.

The following paper companies and foundations have contributed l support to date: St. Regis Paper Co., Black-Clawson Co., Con- a Foundation, Landegger Foundation, West Virginia Pulp & per Co., F. E. Bahrenburg, Champion Paper Foundation, Finch, yn & Co., Hammermill Foundation, J. P. Lewis Co., Mead Corp. ndation, Sealright-Oswego Falls Corp., Nopco Chemical Co., gel Community Foundation, S. D. Warren Co., Weyerhaeuser and Hamilton Paper Co.


**Carefully Controlled Coordination**

between felling and utilization of wood would make our forests an inexhaustible source of raw material for many commodities. The hardboard industry, assisted by machinery manufacturers, has indeed made noteworthy progress towards this end by the development of its high quality products.

There were many troublesome problems to be solved, among which Drying was far from the least. A uniform final moisture content of the dried wood chips is absolutely essential.

The long-sought solution to the Drying problem has been found by BUTTNER with the development of the

**BUTTNER JET DRYER**

(Federal German and Foreign Patents)

a completely new design for wood chips, sawdust, wood fibers, bagasse and similar products. The BUTTNER JET DRYER has proved its efficiency and reliability in more than 70 installations. Technicians in this field will appreciate the performance data that follows:

| | |
|---|---|
| Capacities | Various sizes up to 66 tons per hour according to initial moisture content and heating method |
| Water Evaporation | Up to 44 tons per hour according to initial moisture content and heating method |
| Final Moisture | As desired |
| Heat Requirements | 1450 to 1630 BTU pe pound of water evaporated |
| Method of Heating | Steam, hot water, combustion gases, or combination of oil and waste wood fines |
| Controls | Fully automatic |
| Special Advantages | Quick adjustability to variable initial moistures |
| | Outdoor installation if desired |
| | Lowest operating and maintenance costs |

For further information write for Bulletin 1030E

BUTTNER SINCE 1876

BUTTNER WORKS Inc.,
52 Vanderbilt Ave. New York 17, N. Y.
BUTTNER-WORKS (Canada) Ltd.,
P. O. Box 688, Montreal, P. Que.

## NAMES in the NEWS

Seven members of the Forest Products Research Society have accepted positions in the research division of Weyerhaeuser Company.

**Dr. W. T. Nearn,** former associate professor at Pennsylvania State University, is assigned as professional specialist in the pioneering research department of the division's Seattle branch. **R. H. Kunesh** is working with him as a technologist.

**G. P. (Bud) Urling,** formerly with the Timber Engineering Company in Washington D. C., and **H. G. Freeman,** who recently returned from Finland, are research scientists in Weyerhaeuser's Longview, Wash., laboratory.

Also at Longview are **K. H. Bassett, R. O. Brunner** and **R. L. Corbin,** technologists.

**Wayne K. Murphey** has been named assistant professor of wood utilization at the Pennsylvania State University. His appointment fills the vacancy created by the resignation of **Dr. William T. Nearn,** who has joined the research and development division of the Weyerhaeuser Co. in Seattle.

**Martin E. Craine,** formerly deputy state forester of Utah, has been appointed forestry staff assistant for the Western Pine Association in Portland, according to an announcement by **Ernest L. Kolbe, chief forester.** In his new work, Mr. Craine will help supervise the Western Pine tree farm program in 12 states.

**Roscoe R. Rau,** executive vice president of National Retail Furniture Association, recently told of the appointment of **David J. Thomas** to NRFA's executive staff as director of the organization's educational division.

Appointment of **Gerry P. Re** as technical service manager and **Howard J. Wood** as a plywood service representative of the Western Operations Department of The Borden Chemical Company, has been announced by **R. T. Hanson,** general manager. In his new position, Mr. Re will be responsible for technical service to the plywood, particle board, hardboard, and lumber gluing industries in all states west of the Rockies. Mr. Wood will be responsible for technical service of the company's plywood accounts in the Grants Pass Oregon area.

**George T. Morgan, Jr.,** research associate with the Forest History Society, St. Paul, Minn. has been named winner of the Marion F. McClain Award in Pacific Northwest history for his biography of Colonel William B. Greeley entitled, "William B. Greeley; A Practical Forester, 1904–1928."

**Thomas A. Marshall,** Jr., has been elected executive secretary of the American Society for Testing Materials by its Board of Directors, it has been announced by **Dr. A. Allan Bates,** President of ASTM.

**Willard P. Burdakin** has joined Wheelabrator Corporation, Dust and Fume Control Division, Mishawaka, Indiana, and has been assigned to a seven-state territory, where he will serve as sales engineer.

**Ralph Bescher,** Koppers Company, Inc. and **Bill Penoyar,** NLMA, are allies in an attempt to persuade the Pennsylvania Turnpike Commission to use wood posts instead of steel in the construction of a median guardrail on 100 miles of the Turnpike. (NWPP Fortnightly Review, September 20, 1960)

**John A. Collinge,** president, The G. M. Diehl Machine Works, Wabash, Ind., has announced three promotions recently. **William A. Mitchell** has been appointed general sales manager; **Larry Olmstead** has been promoted to secretary and assistant treasurer of the firm; and **Robert G. Miller** has been named chief engineer.

The 1961 president of the Summer & Casual Furniture Manufacturers Association is **Victor Reiter,** sales manager for Lawnlite Co., Miami, chosen at SCFMA's annual meeting and election, October 16.

Koppers Company, Inc. has appointed two men to new positions recently. **Fred C. Foy,** chairman of the board and president, told of the appointment of **Jack R. Rice** to the post of director of procurement and vice president, and the naming of **Alfred E. Jones** to the position of assistant director of procurement.

## EMPLOYMENT Opportunities

### Positions Offered

E–402—Sales trainees age 21 to 35 to join century-old company serving the retail furniture dealers. Training held in company showrooms and factory, leading to excellent selling career. Furniture experience preferred, but not necessary. (Nov.)

E–404—Experienced technical writer-editor, Madison, Wisc. Permanent position under federal civil service, liberal vacation and sick leave, excellent working conditions. Write, edit official reports, bulletins, handbooks, journal articles on all phases of forest products research. Salary $6,435 to start. Write Personnel Officer, U. S. Forest Products Laboratory, Madison 5, Wisc. (Dec).

Research and Development in the recently consolidated laboratory of the Masonite Corporation. Wood Technology degree required plus minimum of five years' lab or substitute experience in converted Wood Board Products. Age to 35. Location in pleasant Chicago suburb. Send complete resume' and salary requirements to:

L. H. HUFF, MASONITE CORPORATION
ST. CHARLES, ILLINOIS

### Employment Wanted

595—Position desired in production or quality control in wood manufacturing or wood using industry. B.S. in Wood Technology from the University of Michigan and Forestry-Engineering degree from Europe, plus 18 graduate credits in Business Administration. Four years supervisory experience in wood products industry. Married, age 34. (Nov.)

621—Position wanted in plywood production or quality supervision. No degree, but 20 years experience in adhesives research control and technical service, plus 5 years plywood production control and supervision in pine, fir, hardwood, and specialty mills. Foreign offers invited. Age 46, married, 3 children, (Nov.)

622—Supervisory experience in lumber processing, fabrication, and merchandising. Forestry education. Preference Minnesota or Wisconsin. Age 59. (Nov.)

624—B. A. from Grinnell College, Grinnell, Iowa, in Bus. Adm. Has been associated with woodenware production, retail building materials, or home building for the past 22 years. Principally in business for himself. Wishes job with a firm with interests in his own field. (Dec.)

## What's New in Technical Publications

*Single Copies of the Following Reports are Available Free Upon Request from the Director, U.S. Forest Products Laboratory, Madison 5, Wis.*

A review of the present and potential use of wood as a source of raw material for the chemical industry is contained in the report entitled "**Chemical Conversion Products from Wood,**" **No. 2179.**

In Report **No. 2195, "Pulping and Papermaking with Asian Grasses—Ekra, Khagra, and Nal,"** is an account of the experiments that satisfactorily produced various grades of papers from sulfate pulps of three Asian grasses.

A revision of **Report No. 1449, "Facilities for Pulp and Paper Research at the U. S. Forest Products Laboratory,"** brings up to date the description of objective equipment and operations used to conduct research in the pulp and paper fields at the Laboratory.

In the series of Equipment Survey Notes **Report No. 1637–27, "Wyssen Gabler System,"** describing timber harvesting methods in rough, mountainous areas, was revised.

The results of research to determine the minimum spacings of sixpenny and eightpenny common wire nails under lateral loading are presented in the report titled **"Spacing of Sixpenny and Eightpenny Wire Nails in Douglas-Fir Mul Nail Joints," No. 2155.**

Two reports, **No. 444, "List of Publications on Pulp and Paper,"** and **No. 7 "List of Publications on Box and Gr Construction and Packaging Data,"** publication listings that were revised to include the latest source material.

FPRS FOREST PRODUCTS JOURNAL VOL. X, NO. 11 NOVEMBER, 1960

**A METHOD FOR PROPORTIONING**

# Resin and Wax in Particleboard[1]

JOHN E. BALINT

General Manager, Controls and Communications Company, Eugene, Oregon

**Additives in particle boards make up 40 to 60 percent of direct manufacturing costs. For an average size plant this could run to about $375,000 a year for wax and resin. If precision controls save only a small percentage of additive cost, they will quickly pay for themselves.**

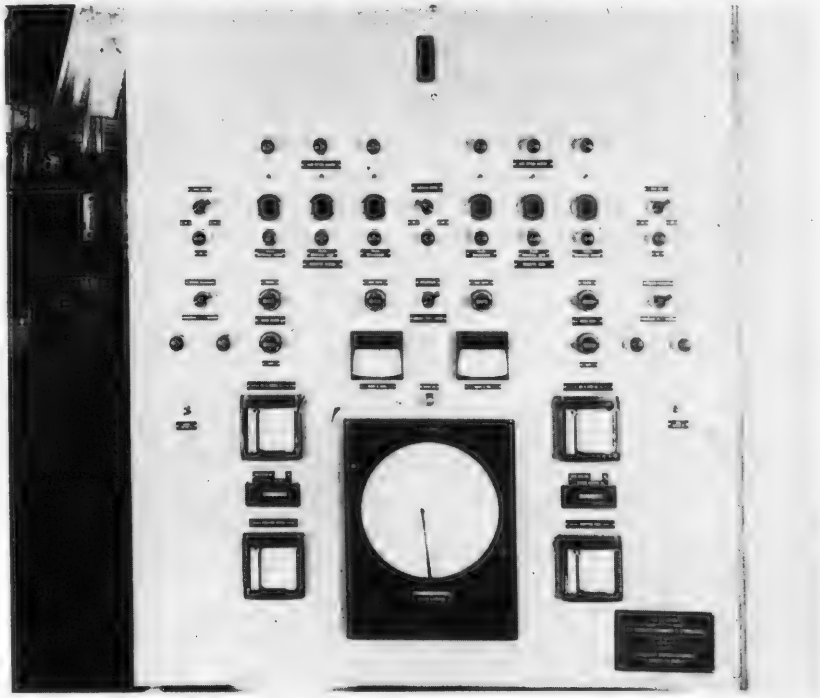


Fig. 1.—Layout of operating panel is symmetrical, with resin controls on right, and wax controls on left. Subassemblies are housed in the same cabinet at the left of the panel.

IN THE MANUFACTURE OF PARTICLE boards of various types, the accurate proportioning of resins and waxes to wood weight is of considerable importance. In many systems the wood-particle flow rate cannot be kept constant, and the problem arises of accurately proportioning the additives to follow the variations in wood weight. Any improvement in the accuracy of proportioning is reflected not only as a saving of expensive raw material, but also as an improvement in the consistent quality of the finished board. The need for over-proportioning to be on the safe side is eliminated if accurate proportions can be specified and maintained in production.

The system to be described was designed as an addition to an existing board plant, and some of its features represent specific compliance with the requirements of that plant and its process. However, the general concept is broadly applicable to any system requiring the precise mixing of additives with the wood particles. As a matter of fact, a similar system has been installed for injecting hot wax in a plant that had previously injected a mixture of resin and wax emulsion.

## Design Considerations

The chief reason for making a process automatically controlled or "automated" is to minimize the effect of the human element. In this case, no saving in manpower was sought, but rather, a precise and tireless variation of two process components in accordance with the relatively uncontrollable variation in the third component: the wood weight.

Minimizing the effect of the human element further dictated that the operation of the system be made as simple and foolproof as possible. Since the final task of the control is to deliver a given percentage of additives to the wood particles, operating settings are made in terms of these percentages.

Keeping records of process variables is an invaluable part of any control system. This is particularly true where production samples are analyzed by quality control some considerable time after the samples are manufactured. The adequate use of recording instruments assures that quality control will always know what went into a given board.

An automatic control system would be incomplete if it did not include an alarm system to indicate malfunction. The alarm system incorporated into this control gives both a visual and audible indication of any malfunction that might affect the mixing process.

An interesting design requirement in this particular application was the need for a time delay between the weighing of the wood particles and the injection of the additives. This was dictated by the fact that the weighing scales were some 60 feet and 30 seconds transit time from the mixing drums. A pumping system that had instantaneous response would have pumped into an empty drum before the wood arrived, stopped pumping into a full drum before the wood had left, and proportioned to what was to come 30 seconds later rather than what was there. A rather simple device was developed that integrates the wood-weight signal in 2-second increments and delivers these increments to the pumping system 30 seconds

[1] Presented at the Wood Industries Conference, Portland, Oregon, September 10, 1959; approved for publication March 11, 1960.

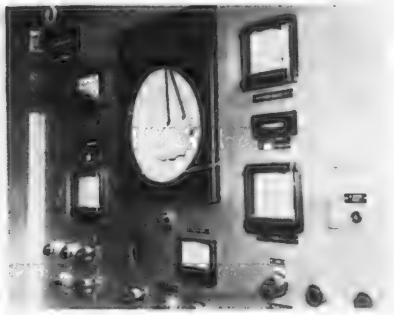


Fig. 2.—Control panel in operation when wood flakes are being run. Wood-rate record shows the irregular feeding.

later. In this way, the wood and the additives are always "in step" in the mixer.

The control engineer is always faced with several choices of control instruments. Pneumatic controlling recorders are available with a high degree of sophistication, and a pneumatic control system was considered in detail. It was found that the cost was almost exactly the same as that of the electrical and electronic system developed. Aside from the difficulty of providing the delayed actuation with pneumatic controls the over-riding factor of ease of maintenance dictated the selection of the control system.

This control system has only seven tube types, plug-in electronic circuit elements, and uses identical sub-units for various functions wherever possible. Most of the components are of a type that is familiar to a mill electrician.

As a safety factor, the function of controlling, recording, and alarming are completely divorced. A fault in the relatively complex electronic recording instruments will not affect the proper operation of the control and will not cause a shutdown.

### Performance Specifications

a) Wood particles are weighed on two conveyor scales, equipped with totalizers, at an individual or combined minimum rate of 5000 pounds per hour and a maximum rate of 15,000 pounds per hour.

b) The resin solutions pumped to the mixer are either urea formaldehyde in a 60 percent solution or phenol formaldehyde in a 30 percent solution by weight. The resin solids-to-wood ratios are adjustable up to 7 percent by weight for urea resins and up to 6 percent by weight for phenol resins.

c) The wax emulsion pumped to the mixer contains 45 percent wax solids by weight. The wax solids-to-wood ratio is adjustable up to 2.0 percent by weight.

d) The system maintains an accuracy of better than $\pm$ 1 percent of the maximum pumping rate based on the total wood weight derived from the totalizer.

### Details of System

#### Controls Provided

a) Resin-to-wood percentage ratio setting.
b) Wax-to-wood percentage ratio setting.
c) Proportion resin solids to resin liquid.
d) Proportion wax solids to wax liquid.
e) Correction setting for percentage wood-moisture content.
f) Manual or automatic operation of discharge rate of resin pump.
g) Manual or automatic operation of discharge rate of wax pump.
h) Operation control; both manual and automatically interlocked with wood conveyor.

#### Recording Functions

a) Circular-chart two-pen recorder for wood weight on each weighing scale.
b) Strip-chart recorder and indicator for resin delivery rate.
c) Totalizing counter for resin delivery.
d) Strip-chart recorder and indicator for percentage of resin solids to dry wood weight.
e) Strip-chart recorder and indicator for wax delivery rate.
f) Totalizing counter for wax delivery.
g) Strip-chart recorder and indicator for proportion of wax solids to wood.

#### Alarm Functions

a) No resin delivered.
b) Resin pump overpressure.
c) Percentage resin solids to wood over or under limit.
d) No wax delivered.
e) Wax pump overpressure.
f) Percentage wax solids over or under limit.

#### Pumps

Two positive-displacement pumps are used with sufficient capacity to pump the required gallonage. They are driven by d-c motors with Thyratron tube power supplies controlled by the control system.

The listing of the various controls and recording instruments illustrates the advantage of the fundamental approach to additive proportioning; namely, varying the pump RPM rather than the pump-stroke length. With variable pump RPM, a tachometer generator driven by the pump will provide a setting means to accommodate desired rates of additive proportioning. The tachometer-generator voltage can be recorded on a chart for a permanent record of the additive rate in terms of both quantity and percentage. A stroke counter on the pump totalizes the amount pumped. If a variable-speed drive is used on the pump, then, with a few more control components, the wood weight can be permitted to vary, with only occasional manual adjustment to keep up with production, and the difficulties of keeping the wood rate constant are eliminated.

### System Operation

The entire control system, with the exception of the pumps, is housed in a single cabinet that is pressurized with a filtered blower to keep out wood dust. When the cabinet doors are opened, the blower is turned off and an overhead light illuminates the interior of the cabinet.

Figure 1 shows the operating panel. Subassemblies are housed in the same cabinet to the left of the panel. The layout is symmetrical with the resin controls on the right and the wax controls on the left. The large two-pen circular-chart recorder in the center records the instantaneous wood weight, derived from the scales as a pneumatic signal. The upper right recorder records the resin pump tachometer-generator voltage and is calibrated in gallons per hour. The counter below it counts the pump strokes and by use of a calibration factor, totalizes the gallons pumped. The recorder below the counter indicates and records the actual percentage of resin solids to dry wood weight being delivered. The

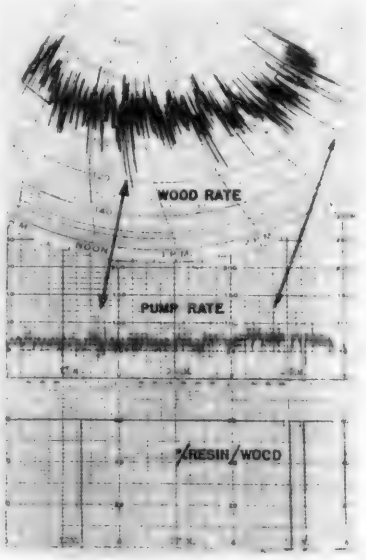



Fig. 3.—Record of wood rate, pump ra and proportion of the percentage of re solids to wood.

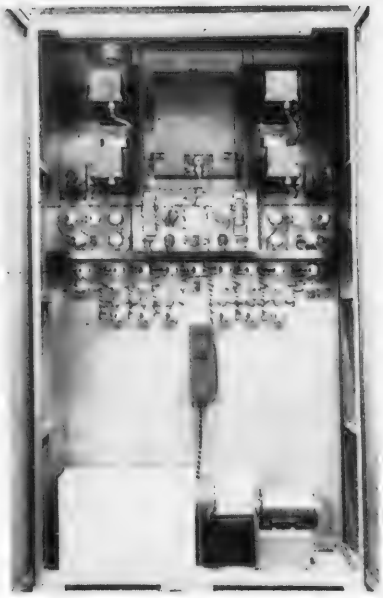


Fig. 4.—Rear view of control panel. Pressurizing blower is at bottom.

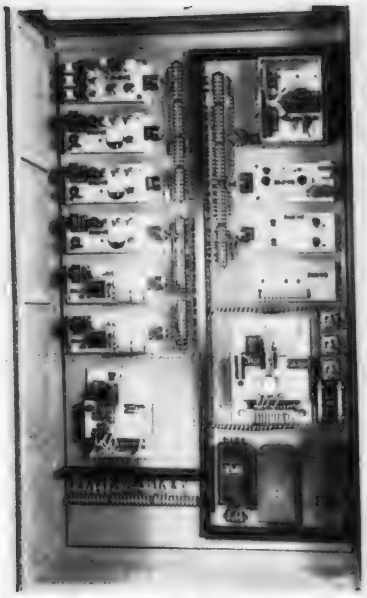


Fig. 5.—Layout of subassemblies at the left of control panel.

door to the right gives access to the calibrator that sets in the factor for resin-solids contents of the mixture being pumped and a factor for wood-moisture content. The dial below the recorder sets the automatic resin pumping rate. The switch to the right selects between automatic proportioning control and manual setting of a constant pumping rate by the dial to the left of the switch. The pilot lights above the switch indicate whether operation is manual or automatic.

The switch next below turns on the primary power to the pump drive and the pilot light above it indicates that power is on. The pilot light below the circular chart recorder lights when the wood weight falls below the minimum level or the wood conveyor is stopped. The switch below is the manual operations start-stop switch.

The center-zero meters to the right and left of the switch are alarm contact meters on the wax and resin percentage settings. They are set to center zero by means of the dials below them when the desired percentage rate is achieved. Full-scale deflection of the meters is $\pm$ 5 percent of maximum pumping rate. The alarm contacts are usually set to $\pm$ 1 percent.

The switch below the "operations" switch turns on the primary power to the control system and the pilot light above it indicates when the control system is on. The main 440-volt circuit breaker is below.

The alarm system pilot lights are grouped vertically with a green light above to show normal conditions, a large red light to show the nature of alarm, and below a toggle switch to silence the alarm bell. The red light below the toggle switch goes on whenever the bell is silenced for that particular alarm function. The alarm functions are: percentage off limits, pump overpressure and pump underpressure.

Figure 2 is a close-up of a portion of the control panel during actual operation. At the time the picture was taken, wood flakes were being run. These feed very irregularly, as shown by the wood-rate recorder. Note that the "gallon" chart follows the excursions of the wood chart, but the percentage chart remains constant.

All the settings are made by means of microdials that present a three-digit indication of the setting of the ten-turn precision potentiometers that are used. The potentiometers are linear to 0.3 percent so that direct percentage calculations can be made.

In practice, the compensation for resin-solids content of the additive and wood-moisture content is very simple. The wood technologist sets a correction factor for resin-solids content of his additive into the "% Solids" dial behind the locked panel. The factor is derived from a calibration curve based on bone-dry wood. Then, the automatic resin-rate dial is adjusted until the desired percentage of resin solids to wood is indicated on the chart, (e.g., 5 percent). This would be the correct setting for 100 percent dry wood. If his wood is only 90 percent wood and 10 percent moisture, he notes the reading of the rate dial, (e.g., 60.0) and resets it to 90 percent of the reading (ie., 54.0) to pump 10 percent less resin.

Now the percentage chart will read low by 10 percent of his previous setting (i.e., 4.5 percent). Next he resets the "% Solids" dial until the chart again reads the desired percentage (i.e., 5.0 percent). Now he will pump and record actual resin solids to bone-dry wood weight. Actually, these steps take longer to describe than to execute.

Figure 3 is a simultaneous record of wood rate, pumping rate and percentage resin solids to wood. This illustrates the wide excursions in wood flow rate for certain types of particles. The percentage of additives to wood remains constant as the pumping rate follows the wood rate.

Figure 4 is a view of the rear of the control panel. The pressurizing blower is at the bottom. Air intake is through a filter at the bottom of the cabinet.

Figure 5 is the left side of the cabinet with the doors removed. The upper right enclosure, shown with its lid removed, is the time-delay device that delays the wood-weight signal for 30 seconds. It consists of a commutator driven by a synchronous motor at 2 rpm. Each segment of the commutator is connected to a capacitor that is charged by the incoming weight signal brush. As the commutator revolves, the capacitor charge is picked off 30 seconds later by a second brush and is used as the control signal.

The upper left chassis contains the power supply for the weight-to-electric transducers and the relay system for starting and stopping pumping as the wood conveyor is stopped and started.

The three chassis below are identical and interchangeable. They are differential d-c amplifiers that generate the control voltages for the pumps and regulate the pumping rate. The upper amplifier amplifies the wood-weight signal, the middle amplifier regulates the resin pump, and the lower amplifier regulates the wax pump.

The next lower chassis are the divider servos that divide the actual pumping-rate signal derived from the pump-driven tachometer generator, by the wood-weight signal, to give the percentage indication functions. These two chassis are identical and interchangeable. One serves the resin system, the other the wax system.

Below the dividers is the wax-pump-drive power supply and to the right is the resin-pump power supply. Below the time-delay commutator is the alarm-circuit relay chassis and below that is the tachometer-generator calibrating chassis. Switches and fuses for cabinet lights, blower, and so on, are on the remaining chassis.

Figure 6 shows one of the positive-displacement pumps installed. The feedback tachometer generator is mounted between the two pump heads. A small transformer-iron vane is attached to the pump crank and

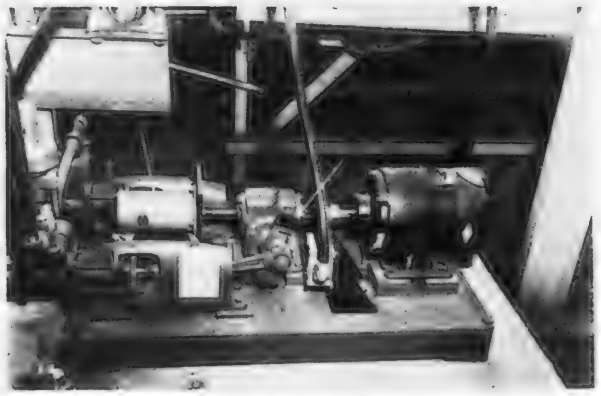


Fig. 6.—Installation of positive displacement pump.

travels through the slot of the proximity limit switch to actuate the pump-stroke counter.

Figure 7 is a schematic block diagram of the control system. Since the resin and wax control are the same, only the resin system is shown. Starting at the left the air signal, provided by the scale manufacturer, is recorded as the wood weight.

Voltage from a regulated power supply is varied by the weight-to-electric transducer to give the control signal. The transducer uses a precision potentiometer mounted on the scale-integrating mechanism and reflects no unbalance on the scale.

The combined weight signals are fed to the time-delay commutator and from there to the wood amplifier. A relay amplifier, fed from the wood-amplifier output, detects the absence of a wood signal and performs the necessary switching functions to stop the pump by feeding a negative voltage to the control amplifiers. When the wood signal exceeds the minimum specified, the output of the wood amplifier is fed to the resin amplifier through the automatic rate-adjusting potentiometer. The resin amplifier feeds the d-c power supply which serves the pump motor.

A proximity limit switch is actuated by the pump crank to pulse the pump-stroke counter or integrator. The tachometer generator attached to the pump motor shaft provides the signal for the resin gallons-per-hour recorder and also supplies the feedback signal for the resin amplifier. The resin amplifier is designed so that its output will adjust until the feedback signal exactly equals the input signal.

The same feedback voltage, which is a measure of the pumping rate, is compared with the wood signal appearing across a motor-driven potentiometer.

Any difference between the wood signal and the pump signal is amplified to drive the servomotor until the voltage from the motor-driven potentiometer is exactly equal to the pumping-rate voltage.

When the tachometer is driven at exactly the correct rate, its voltage is equal to the amplifier input voltage. If the amplifier input voltage, derived from the wood signal, is divided in half by the rate potentiometer and the tachometer feedback voltage is the same, then the motor-driven potentiometer will also have to divide the wood signal in half to make the differential input to the servoamplifier equal zero. In this way the physical setting of the potentiometer (in this example at midpoint) is the quotient of the division of the pumping rate by the wood rate.

A second potentiometer, mechanically ganged to the motor-driven potentiometer is supplied from a regulated 100-volt power supply. The voltage derived from this potentiometer is numerically equal to the percentage between wood and pump signals; in the example: 50 volts of 50 percent. This voltage is used to actuate the "% Alarm Meter." When the desired percentage is attained, the meter is "zeroed" by the "Alarm Zero" potentiometer which is manually set to apply a voltage equal to the percentage voltage to the second meter terminal. If the percentage voltage changes after the zero setting, the unbalance will be indicated by the meter and sound the alarm.

The "% Solids" adjustment divides the percentage voltage by a factor derived from the percent solids content of the additive being used and, as previously described, by the wood moisture content factor. This voltage is then recorded as the final percent solids-to-dry-wood ratio.

The remainder of the control system consists of manual speed control of the pumps, various relays to perform necessary interlocking and alarm functions, and solenoid valves in the pump input lines to prevent gravity feed through the pumps when the system is shut down.

## Conclusion

According to studies made by Timber Engineering Company and others the cost of additives in a particle board process represents 40 to 60 per cent of the total direct manufacturing costs. For an average size plant, the manufacturing costs are approximately three-quarter million dollars a year. Fifty percent of this is about $375,000 a year for wax and resin.

Even a small percentage saving in the quantity of additives used, that is made possible by precision control, will quickly pay for the cost of the control and result in substantial direct savings in expenditures for additives. Indirect savings will also result from close control of the quality of the finished board and adequacy of manufacturing records.

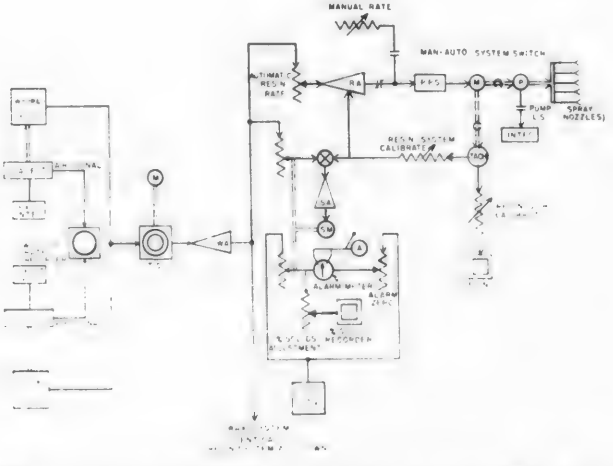



Fig. 7.—Schematic block diagram of resin control system. (Wax system is identical.)

# Pendulum Cutting Test Standardization

## AND PERTINENT CUTTING FUNDAMENTALS[1]

## PART II

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**Fundamentals of fiber severance and chip formation were discussed in Part I. In Part II, discussion of chip formation is concluded and three forms of a standard cutting tool are described.**

TRIPLE EXPOSURE of the dynamometer in action. A single sawtooth mounted on one pendulum swings into a wood block mounted on another pendulum.

THE CHIP CUT by a sawtooth is not free to clear the cutting tool until the sawtooth completes its passage through the workpiece, but it must move away from the active cutting edge. A controlled movement or flow of the chip may be obtained under some conditions, and the effectiveness of the flow control is related to gullet outline.

Chip flow is but one factor in designing a tooth form. Sawdust chambering capacity of gullet area must be considered also. The use of equal gullet-edge lengths for the four shapes of Fig. 13 resulted in some difference in pitch or tooth spacing, and the comparison of gullet areas is best made on the basis of relative area per unit length of saw band. If the value for gullet A is taken as 1.0, then the relative gullet area for B is 0.984, for C is 1.012, and for D is 1.120. Obviously, form D provides the greatest sawdust space per unit length of blade, in addition to the most favorable conditions for chip-ribbon flow.

Chip flow is not limited to the ribbon type. Very thin chip ribbons may buckle and break up in a confused manner, while tooth design and strength characteristics of the wood itself sometimes have major effects on chip flow.

The relationships between shear, cleavage, compression, and bending stresses under impact conditions determine the character of the wood failure during cutting. For a species such as shagbark hickory (*Carya ovata* (Miller) K. Koch), the compression and bending at the tooth face during fiber severance and shearing at the sides and across the chip do not appear to reach the fail point for all parts of the fibers. As a result, the energy stored by elastic deformation during cutting is released suddenly as the chip becomes free and reacts against the tooth face to move the chip away from it. Since the resulting movement is more or less in the direction caused by the tooth action (point $P_o$ to $P_2$, Fig. 10A), the additional velocity due to recovery from deformation snaps the chip into the gullet much as a thin cake of wet soap can be snapped from between the thumb and forefinger.

Chardin's Fig. 16 of (1) appears to be an example of this action, and Thunell (8, 9) and Englesson. Hvamb, and Thunell (3) have noted similar particle movements. The energy of elastic recovery, and the particle speed are, perhaps, optimistically indicated in the observations cited. Thunell, Englesson, and Hvamb, used springset saws and simulated a full kerf, but the plexiglas kerf walls had low friction and had the same speed as the saw, thus elimintaing much kerf friction or reversing the direction of its effect at some points. Chardin's observations were made on swaged saw teeth just after they emerged from the cut with no kerf walls or with a kerf wall on only the far side of the gullet. The author's observations were made with swaged teeth on the pendulum machine at rather shallow kerf depths. In every case, then, restrictions on chip movement were far less than those normally present when the cut is made with the tool enclosed on both sides by the wood being sawed. If the velocity added by the elastic recovery is high enough, the chip may move into the gullet into such a position that a true ribbon-like flow of chips cannot develop, resulting in a somewhat scrambled accumulation of chips toward the bottom and back edge of the gullet. When the added velocity is very high, it is conceivable that the chip may cross the gullet and rebound from the far side. Such rebounding, however, is most likely to occur with springset saws, the chips of which are roughly only one-half the width of the kerf and so are able to move within the kerf with considerable freedom. In contrast, the chip cut by a swaged tooth equals the kerf in width and is

The Author: Les Reineke earned his BS in estry from Cornell University, and took a r of graduate study at the Univ. of California. He joined the FPL in 1942.

[1] Presented by title only at Session VI, Wood Machining, FPRS 14th Annual Meeting, June 5-9, 1960, in Montreal, Canada.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3] Numbers in parentheses refer to the Literature Cited at the end of Part I of this paper.

subjected to frictional retardation of its movements. In all likelihood, the energy in elastic recovery is completely absorbed by friction between the chip and kerf walls when a ribbon type of chip flow develops.

The energy in elastic recovery in all cases must be expended within the confines of the gullet, except during the final brief moment when the front of the gullet emerges from the cut while the tooth is still cutting. Energy consumed by friction is, of course, converted to heat. The kinetic energy of particles moving away from the tooth face must be transformed to frictional heat or transferred to the saw or other chip particles by impact. The transfer may restore some energy to the saw or extract some energy from it, depending on relative directions of saw and particle movement. Each impact with the saw or another particle, however, will cause some deformation, and the resulting internal (molecular) friction will convert some of the chip energy into heat.

Eventually, practically all the energy of elastic recovery will be dissipated within the gullet. Although this recovery energy may be high, it performs no useful action and must therefore be charged against the cutting and crumbling of the chip. Prorating this charge between the separate phases of cutting and crumbling would be difficult, as some part of the energy stored in the first phase is transmitted to the following phase, and a similar transfer between succeeding phases takes place. The energy remaining after the last phase, chip crumbling, is dissipated within the gullet as described previously.

One point of minor interest in the distribution of the energy of elastic recovery is that the energy returned to the saw by impact of particles moving in the same general direction as the saw has a net value that depends on the excess of chip velocity over saw velocity. If the chip, on impact, transfers enough energy to drop its velocity below that of the saw, the chip particle must reabsorb enough energy from the saw to bring its velocity back to saw speed. The kinetic energy remaining in the sawdust upon its ejection at saw velocity is a function of that velocity and has been discussed elsewhere (7).

Another point of interest is the resistance of the chip particles to removal from the kerf. Loosely treated as friction, this resistance is a composite of several forces. True frictional resistance occurs between the chip and the tooth face and gullet edge. For certain tooth designs, such as those with inserted-bit saws, a slight projection of the holder may form an obstacle that impedes the flow of the chip.

The sides of chips cut by swaged teeth bear against the kerf walls, and the resultant rubbing is more of an attrition grinding than a pure friction contact. The sides of the chip and the kerf walls are all the product of shear failure, which results in irregular surfaces. These are made more irregular by the sawtooth marks, which are triangular in profile, and by small pits and crumpled fibers that result when the shear plane leads into the kerf wall because of sloping grain. The numerous small irregularities on both kerf walls and chip sides tend to interlock and impede movement, as with two pieces of coarse sandpaper placed face to face. This interlocking of surfaces requires energy to displace mutually opposing projections by deforming one or both enough to permit chip passage, or by tearing loose or rubbing off one or both of the projecting fibers or fiber ends. The effect of attrition of the surfaces in contact is cumulative, increasing progressively from the top to the bottom of the sawed face and from the line of the cutting path at any instant back to the line through the bottoms of the gullets at that instant. This progressive attrition of surfaces may be sufficient to modify the sawing force slightly as the saw begins its cut. Stable conditions will be reached, however, as soon as the cut has progressed far enough into the stock to fully enclose the gullets between the kerf walls.

The interference between the side surfaces is duplicated with the other surfaces of the chip particle arranged spirally or at random within the gullet. There is a great difference in degree, however, in two respects. The velocity of one chip particle in relation to its neighbor is extremely low in comparison with the high velocity of the chip sides relative to the kerf wall. In addition, the minor projecting fibers or fiber ends are over-shadowed by the interference between ends, tops, and bottoms of the chip particles as soon as they lose their initial smooth ribbon alinement. The resulting action is similar to grinding by tumbling, but the strong interference between particles precludes as extensive grinding action unless excessive pressure from overloading the gullet takes the place of high velocity. In this event, the pressure will affect the resistance between chip sides and kerf walls even more drastically, causing the disporportionate increase of power that is required when gullet capacity is exceeded.

**Flow of Shavings:** The flow of a chip ribbon in a saw gullet has some parallels in the movement of shavings over the knife edge and knife holder of planers, jointers, shapers, and other moving knife tools. The friction on the edges of the chip is absent, of course, but the width of shavings insures more stable alinement than is obtained with sawdust, and the chambering of a long stream of shavings is not required. Control of direction and velocity of ejection of shavings could be of great value in facilitating their pickup and removal. Reduction of planing defects in the form of chip marks, more complete removal of shavings, and noise reduction may be some of the benefits of control of chip movement. The importance of chip movement, independently and as component of cutting energy, must be recognized in the design of tools to be used in making standardized tests of cutting forces.

### Standard Tool

The total energy in sawdust is made up of both kinetic energy and heat. The heat energy is produced by internal friction in deformation during cutting, friction between the chip and the kerf walls, friction between the chip and the tooth face and gullet edge, surface friction between rubbing particles, or internal friction during crumbling of the chip. Some of the kinetic energy of the chip may be converted to heat energy before the chip leaves the kerf.

The energy converted to heat by these several processes will vary with the length of cut, chip thickness, gullet size and form, and other factors. The residual kinetic energy in the sawdust can be calculated accurately when the sawdust has been enclosed by the kerf walls and gullet, except for particles at the end of the cut that escape directly from the emerging gullet without first passing through the cycle of

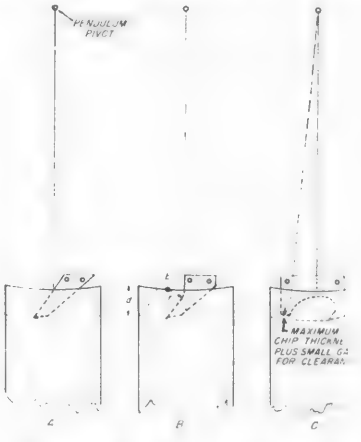


Fig. 14.—Three forms of cutting tools under consideration in standardizing the tool for use in pendulum dynamometers. In form A the chip ejection velocity is determined by both pendulum velocity and tool face angle. In form B, the fillet E eliminates the effect of face angle on chip ejection velocity. In form C, the enclosed chip space prevents escape of particles at velocities exceeding pendulum velocity.

movement within the gullet. Such escape will be least when the gullet is well filled as the result of a long cut or a thick chip, and a long cut will reduce the relative size of any error. Conversely, a light and short cut will provide a greater opportunity for direct escape of particles at the end of the cut, and the shortness of cut will make the error relatively larger.

This error from the escape of particles at the end of the cut probably is very small compared with the differences in sawdust energy that is converted to heat in gullets of different sizes and shapes and with different amounts of enclosure by the kerf walls. For consistency of conditions in a standard test, specifications for the standard tool should not be limited, therefore, to the hook angle. The exact shape of the front edge of the tool, including any gullet, should be specified. To hold the kerf wall friction within small limits, the minimum and maximum height of kerf walls (depth of kerf) also should be specified.

No specific form of tool is proposed here, but three forms merit consideration. One is a straight tool (Fig. 14A) in which the hook angle of the tooth face is continued for the full length of the tool shank. This would be equivalent to a planer or similar knife except for the difference between a trenching or grooving cut and a surface shaving. If a shallow kerf is specified, in the range of perhaps 10 to 15 millimeters, the results of tests may be applicable to both sawing and planing by use of the ratio between cutting forces in enclosed and open cuts. The ejection velocity of a chip stream following the tool face, however, will vary with the hook angle.

The second tool form to be considered may be described as a tooth face of specified angle and length, a tool shank alined with a radius through the pendulum pivot, and a fillet of specified radius joining the tooth and shank (Fig. 14B). With the kerf walls extended above the bottom of the cut to the point of tangency between tool shank and fillet, the chip flow at the ejection point E will be perpendicular to the cutting direction at any instant. The kerf walls should not, however, project so far that excessive energy will be absorbed by friction between the chip edges and the kerf walls. To maintain the kerf walls at a given level or within a limited range, an electrically driven high-speed rotary cutter may be mounted on the pendulum arm for cutting the kerf walls back to size after every test cut or group of cuts.

With this type of tool, the velocity of the ejected sawdust will be the resultant of the radial sawdust velocity along the tool shank (equal to the tangential velocity $V_T$ of the cutting edge) and the tangential velocity $V_{Sh}$ of the tool shank at the emergence point E, Fig. 14B, or

$$\sqrt{V_T^2 + V_{Sh}^2}.$$

Since $V_T$ and $V_{Sh}$ are approximately equal when the pendulum radius is long and the cutting depth $d$ is short, the resultant $V_R$ may be taken as

$$V_R = V_T \sqrt{2} = 1.414 V_T$$

The distance $d$ must be quite short, however, so that any failure of the final portion of the chip to reach this velocity will not have an appreciable effect. The dotted line at the left end of the cut in Fig. 14B is the length and position of chip affected when the cutting edge reaches the exit end, where there is no more uncut stock to provide the reaction to push the chip along the tooth face. The length that is affected extends from the cutting edge to the upper end of the fillet, and the effect is the difference between mean velocity of this section and $V_R$, plus the loss due to friction as the chip sweeps over the area to the left of the dotted line.

It may so happen that an appreciable portion of the sawdust is ejected on a path that does not follow the tool and shank faces because of the "snapping" type of chip release. Photographs may be required to detect or verify such action. If present in any major amount, kinetic energy will be difficult or even impossible to compute with either of the tool types of Fig. 14A and B.

Recourse to a third form of tool would be necessary to retain the sawdust during cutting to regain some of the excess energy contained in the chip particles. Some form of saw-tooth gullet would be required with a capacity sufficient to hold the sawdust from the thickest chip to be taken across the test block without crowding and without excess capacity. The forward side of the gullet should extend in a radial line from the pendulum pivot, or even be tilted more than the tooth face (Fig. 14C), to provide free discharge of sawdust without transfer of any of its kinetic energy to the pendulum once the cut is completed. The forward side of the gullet, however, should extend as far as possible toward the line of cutting without rubbing against the bottom of the kerf during cutting of the thickest chip in a standard test. A tool of this type, in addition to capturing sawdust of any flow pattern, will recover the energy of excess chip velocity and reduce any excess particle speed. The chip-ejection velocity will always equal tool velocity, thus avoiding the higher ejection velocities of the first and second types and the variation with hook angle of the first type.

### Treatment and Selection of Test Blocks

In the various stages of processing wood in which saws are used, the condition of the wood may be classed as green unfrozen, green frozen, air dry, or kiln dry, and any one piece of wood may be subjected to sawing while in each of these conditions.

**Treatment of Material:** The condition of the wood has an appreciable effect on the energy required in sawing and on the tooth design needed for the most effective operation. Test material used to establish the sawing characteristics of the wood should therefore be maintained in the condition in which the wood is to be tested. Studies at the U. S. Forest Products Laboratory show that wood more than 1 or 2 centimeters in the fiber direction cannot be restored to a green condition, with cell cavities filled in the sapwood, after drying has removed water from the cell cavities. This cell-cavity water can be significant in sawing frozen wood or in lubricating and cooling the saw in sawing unfrozen green material. A further reason for not attempting to restore dried wood to a green condition by soaking is the probable presence of stresses and small surface checks or internal failures caused by drying. Drying defects cannot be eliminated by soaking, nor can differences between heartwood and sapwood moisture content be restored in pieces that contain both types of wood.

It is desirable, then, that all wood intended for green-condition tests should be retained in its original green condition. Good sampling practices can be applied to green material, even though some of the projected tests are to be made at other moisture contents. Direct determination of specific gravity by electronic and radioactivity techniques, however, may eliminate the need of samples.

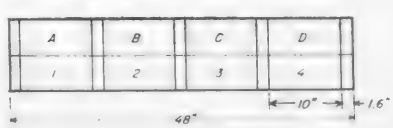


**Fig. 15.—Sampling of green material for determining dry density. The 10-inch pendulum test pieces are kept in original condition until dry densities are determined from the 1.6 inch sections, after which the 10-inch test pieces are assigned to the desired density and treatment groups.**

**Density Determination by Sampling:** Samples in the green condition can be matched for dry density by cutting a narrow piece from one or both ends of each test piece, identifying all pieces, and drying the cutoff ends to determine density. The pendulum test pieces will, of course, have been cut with enough excess length to permit taking the density specimens and will be kept in green condition until the densities of the density specimens have been determined. On the basis of these determinations, the pendulum test pieces can be assigned to density groups and treatment.

Mechanical and Latin Square types of matching can be done in the green condition if the stock is large enough for multiple pendulum test pieces. For example, a board 10 inches wide by 4 feet long may be ripped and crosscut to form 8 pendulum test pieces 5 by 10 inches, plus allowance for density samples. Thus, in Fig. 15, A, C, 2, and 4 can be used for one treatment, and B, D, 1, and 3 for a second treatment. The narrow sections between them serve to determine densities without drying the pendulum test pieces prior to tests that do not require drying.

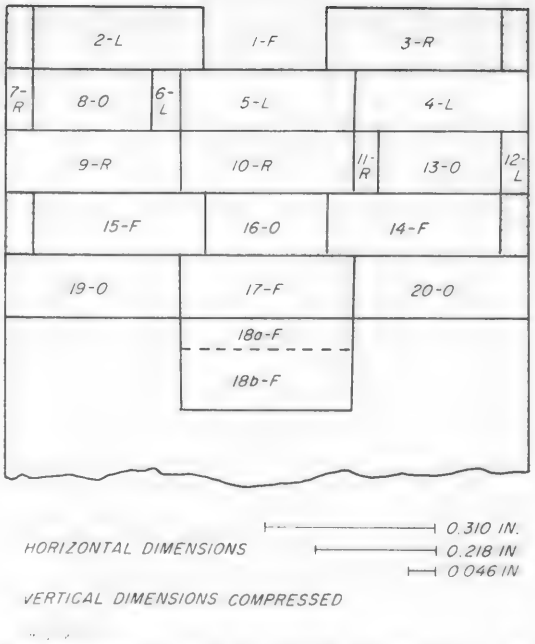


**Fig. 16.—Pendulum cutting test program for determining effects of sides on cuts. Vertical height of blocks schematically represents a set of pendulum cuts. Horizontal dimensions show the width and location of cuts to scale. Numbers give sequence of the sets of cuts. Suffixes signify tool sides engaged in each series: F = full cut, both sides engaged; O = open cut, neither side engaged; L and R indicate left or right side only engaged. Blocks 18a and 18b represent two chip thicknesses for determining tool sharpness at the end of the test.**

**Experimental Design:** The three categories into which pendulum tests may be placed are:

1) Those in which a single type of test is made on a number of samples;
2) Those in which multiple tests are made on a single sample;
3) Those in which a composite sample is used.

Category 1 would include such tests as would be made to determine the average cutting characteristics of a species with a standard tool. As the variable under test is the species, a random sample is required of the species population or a specific subdivision of that population, such as slow or fast growing wood, sapwood or heartwood, or geographic or topographic source of material. Standard statistical procedures provide adequate methods for sampling and for analysis of results in such studies.

Category 2 would include tests in which the variable under test is the tool or the cutting action. Uniformity of material is desirable here to minimize experimental error. This type of test is illustrated in the analysis of side effects (Figs. 8 and 9) for which the various cuts were programmed, as in Fig. 16. Uniformity of test material can be improved by selection, orientation of grain, and use of the composite samples included in category 3. Depending on the objective of the test, material may be selected that has exceptionally straight grain, a uniform growth rate, or other characteristics, such as density, hardness or even specific defects or other aberrations. Species can be selected to provide a desired characteristic of wood structure, such as small or great differentiation of springwood and summerwood, or pores arranged diffusely or in rings.

**Test Block Dimensions:** Dimensions of test blocks must be adapted to the test, and the known effects of cutting actions on the wood must be considered in planning the localization and sequence of cutting conditions. For example, when the test involves only the edge of a saw tooth ¼ inch wide, with no cutting to be done by the corners, the test specimen must be less than ¼ inch in thickness. Some slight splintering along the sides can be expected. Normally, this could be ignored where the width of cut is large, but the relative effect of splintering becomes greater as the width of cut (thickness of test block) decreases. A supporting block placed very slightly below the cutting line on each side of the test block is indicated.

**Grain Direction:** Orientation of grain may be one of the factors studied, but where it is not, it can be utilized to improve the test block. Wood is most uniform along the longitudinal axis, which is the direction of feed in ripsawing, and a test block that is long in the fiber direction permits numerous test cuts with little or no change along the length of a small bundle of cells.

A test block, however, must have appreciable thickness to accommodate the width of the cutting tool, and sufficient width to provide a useful length of cutting path. In a radial direction, wood may change from heartwood to sapwood, and the width of annual rings may vary widely. In the tangential direction, the sometimes irregular curvature of the annual rings changes progressively with distance from the pitch. The percentage of summerwood may vary from one point to another on the same ring, and the width of annual rings in relation to tool width may be such that the tool will be operating more in the springwood than in the summerwood, or vice versa.

The tangential and radial variations may be large or small on a given cross-section, but lengthwise only slow changes will take place in the radial or tangential pattern to influence successive cuts. In a tangential cutting direction, the tool itself, if narrow, may take an unequal sample of springwood from the annual ring it chiefly follows and it will fail to sample many of the annual rings alongside the cutting path. This would be especially disturbing if two or more cutting paths were used on a test block in which the rings were rather straight and parallel to the cutting paths.

When the annual rings are perpendicular to the width of the test block, the cutting path is truly radial and all rings will be cut across by the tool whether only one or several cutting paths are cut. Width or percentage of summerwood of an annual ring may vary progressively along its arc, but the variation in material sampled along each cutting path will be rather minor. Furthermore, if the edges of the test block are made parallel to the longitudinal direction of the rings, no additions to or subtractions from the rings cut along the cutting path will occur as the tool penetrates into the test block. With a tangential alinement of rings, this change would not be avoidable because of the taper of the tree from which the test block is derived. One possible difficulty with the radial (true quartersawed) test block is the mechanical one of pulsating forces as the tool cuts alternately in soft springwood and harder summerwood of ring-porous hardwoods or other woods with sharply differentiated springwood and summerwood zones.

This mechanical difficulty can be relieved somewhat by placing the annual rings at about 45°. For a cutting tool 1.4 times the annual ring width, one end of the tool will be entering (or leaving) the summerwood as the other end is leaving (or entering) the springwood, producing a transition without sharp pulsation.

In general, any direction of annual rings would be acceptable provided each annual ring is crossed only once by cutting path, and the cutting direction (from springwood to summerwood to springwood) does not reverse within the length of the cutting path. This precaution as to cutting direction is suggested because of the differences that have been found in rotary veneer cutting actions when the cutting path crosses the annual rings in the bark-to-pith direction, and when it crosses in the pith-to-bark direction (5). (Force measurements were not made in this study of veneer cutting.) Adherence to the single cutting sequence within the test block is desirable, pending sufficient comparative cutting tests to determine whether or not this factor may be ignored. Such tests should be carried out by making a number of cuts in one direction, then reversing the test block and making more cuts in the same kerf line, alternating the direction of the test block after each group of cuts. Naturally, the first few measurements in each group should be discarded, because they will have been affected by the preceding cuts in the opposite direction.

Energy requirements may be the same, but some differences in cutting action may be anticipated in wood with sharply differentiated springwood and summerwood. The densest and hardest part of the ring is at the outer part of the summerwood band. As the cutting edge encounters this area in the bark-to-pith cutting direction, the full strength of the summerwood band provides support to the fibers being cut, promoting a clean cut. As the cutting edge proceeds across the ring, the fiber density at the cutting edge as well as the fiber-supporting force decrease. In the pith-to-bark cutting direction, however, when the cutting edge reaches the outer end of the summerwood band, the fibers are supported only by the softer springwood of the next annual ring. Rough cutting and splitting below the line of cut may then result.

**Composite Test Blocks:** Securing test blocks that meet requirements as to grain direction, density, growth rate, and the like may be difficult with some species or some specifications. A radial (true quartersawed) test block of sapwood only may not be possible when the species characteristically has a narrow ring of sapwood. This and similar problems could be solved by making up a composite test block of a small number of pieces that have the desired characteristics.

A composite block was used by Chardin (2) in his masterly solution of the problem of identifying sawdust particles in the saw-tooth gullet according to their original position in the block. The composite block consisted of wood strips dyed various colors, assembled with edgewise pressure that was maintained while plywood sides were glued on the assembly. Since glue was applied only to the sides of the strips, there were no glue lines in the cutting path of the saw, making this type of sample ideal for this specific study.

It was necessary in that study to avoid glue lines between strips in order to allow for free and complete separation between sawdust particles from adjacent dissimilarly colored strips, but this requirement does not apply in ordinary cutting-force tests. A test block of edge-glued strips should be satisfactory, if an appropriate glue is used and the number of glue lines is small (2 to 5 or 6). A soft, nonabrasive glue of moderate strength (equivalent to that of the wood) would maintain the strips in position as a unit and would not affect force measurements significantly. The glue lines would eliminate the unwanted equivalent of a crosswise break of the chip between each pair of strips. The strips would not be under pressure during cutting, nor would the strips tend to develop gaps as might occur in thick test blocks held together only by glued side pieces. In addition, laminations several times wider than the test block thickness could be assembled and glued in one operation, then resawed to form several test blocks.

Still another advantage of laminating test blocks is the opportunity afforded for creating a "wide-range" material or for preparing a number of uniform test blocks in which the effects of variations of the wood are at a minimum. "Wide range" material may be made up of laminations representing the species-wide variation of some characteristic, such as density, and the width of each lamination may be proportional to frequency. Perhaps five laminations would be adequate for a test block representative of the species characteristic being studied.

When the scope of an experiment becomes large, such as one in which rate of dulling of different tooth materials is to be determined for different hook angles, the heterogeneity of wood can give rise to irregularities or uncertainties in the results. Composite samples offer some relief from this situation by subdividing the material and reassembling it into test blocks according to Latin Square or other statistical techniques. Thus, from a basic stock of 3 boards of 3 times the length and width of the test block, 9 test blocks can be assembled by the following procedure.

Cut each board into 3 strips and 3 lengths, identifying each piece by board number, strip number, and length number. Reassemble the pieces into 3-lamination test blocks, so that each block is made up of 1 piece from each board and from a different strip and length of each board. Thus, the first test block may be made up from the following three pieces:

Board 1, Strip 1, Length 3
Board 2, Strip 3, Length 2
Board 3, Strip 2, Length 1

and the second block from pieces identified as:

Board 1, Strip 2, Length 1
Board 2, Strip 1, Length 3
Board 3, Strip 3, Length 2

Continuing, the entire set of 27 pieces can be distributed between 9 test blocks with board number, strip number, and length number occurring only once in each block. The sequence of laminations in each test block is unimportant, as energy measurements represent the total, not the individual

pieces. It is important, however, to assemble each set of laminations with the grain properly alined in each piece.

This system can be applied to fewer or more test blocks, as dictated by the size of the study or supply of material. The glue lines may be of no importance in studies relating to the tool, as they will be present equally in all test blocks, but may be a disturbing factor in studies relating to the wood.

**Test Block Size:** The size of the test blocks must be optional to permit specialized tests, but for comparative evaluation of species, some standard test-block design is almost imperative. For such evaluations, two variables, tooth width and feed per tooth, must be considered, with tests at several levels of each variable. This imposes, therefore, a rather severe requirement for uniformity of test material within each set of tests covering the two evaluating variables. The effects of density, moisture content, growth rate, or other factors, however, can be measured on any number of selected test specimens, but uniformity within the specimen is necessary.

As discussed previously, the direction of least variation is the longitudinal direction of the cells (not strictly identical with the axis of the tree because of taper), and the variation that does occur is of a slowly progressive nature. Within the distance of the inch or two used for a single test, such progressive variation can be ignored safely. For a group of tests requiring a sample approaching a foot in length, the effect of any systematic variation often can be reduced to a negligible level by scheduling the various tests in a suitable order.

Variation across the width of the test block—the direction of the cutting path—is high because of the differences between the annual rings that are crossed, but since each cut involves the same annual rings, the mean value remains uniform unless there is a change in the annual rings cut. Such a change is least apt to occur if the test block is quartersawed (annual rings perpendicular to the cutting path). A tangentially sawed test block, with rings parallel to the cutting path, samples only a few rings. The rings cut in whole or in part as the cut progresses along the length of the block may vary, because the rings are not truly circular, and taper in the tree or a sloping grain may bring different rings into the line of the cut.

Variation in specific rings cut may become great if the test block thickness is increased to permit a second cutting path parallel to the first. With a tangentially sawed block, the annual rings cut along one cutting path may be missed entirely by the second cutting path, and the rings cut by each may be radically different. This difference disappears as the ring direction changes from parallel to perpendicular to the cutting path. Use of true quarter sawed test blocks would make it difficult sometimes to get sample material of suitable size, and the cutting action would tend to be pulsating when the springwood and summerwood differed much in hardness. An intermediate ring direction of about 45° would provide smoother cutting action and easier procurement of required sizes for test blocks. The second cutting path in test blocks with intermediate ring direction would miss a few rings cut at the other end of the first path. This change may be negligible, if no sudden change occurred in growth rate in the area of the two cutting paths. The variation between tests made in two parallel cutting paths however, will exceed that between successive tests in a single cutting path even when the ring direction approaches 90°.

The single cutting path type of test block therefore appears to be the most advantageous from several standpoints. In addition, it is adaptable to tests that require numerous cuts. Excessive length in the support for the cutting tool is not required because the standing sides of the kerf can be shortened periodically to prevent interference with the tool holder.

The method of holding and feeding the test block to the cutting edge has some bearing on the testing technique and efficient use of test material. When all tests proceed in the same direction from one end of the test block, any progressive variation in the material will have the same sign for all tests, but if tests proceed from both ends toward the center, the sign of any progressive variation in material will be reversed for half of the tests. The method of mounting the test block in its holder may have a bearing also on the proportion of the block that can be used when cutting proceeds from one end only or from both ends. If holes for bolts or locating pins are used, the distance from those holes to the last cut is lost once when cutting from one end only and is lost twice when cutting from both ends.

Bolting of the test block to the holder requires a zone of sufficient length between the bolt location and the last cutting line to insure freedom of the cutting zone from bolt pressure. This pressure may be rather high if it must take up the turning force applied at the end of the test block by the tool as it makes a cut.

Bolting of the test block to the holder requires the projection of the entire usable length of the block above the plate to which it is bolted, and the entire holder must be advanced by the feed mechanism without changing alinement. Splintering along the exit edge of the test block can be avoided by a movable support, but this would require adjustment prior to each cut.

An alternative method of mounting and feeding the test block may be used. The holder may be in the form of a long, flat plate against which the wide face of the test block rests, and with a perpendicular strip along one edge to serve as a fence against which the exit edge of the test block can rest. The height of the holder is adjusted so that the top end of the fence barely clears the path of the cutting edge, thus acting as a guard against splintering at the exit end of the cut. A flat bar bolted to the plate and fence near the top end holds the test block against the plate. Bolting pressure is regulated to permit sliding the test specimen under the bar during feed without requiring excessive feed pressure. The bar may extend slightly above the line of cut to prevent any spreading of thin kerf walls, or it may be located slightly below the cutting line. Feed may be supplied by a graduated screw that moves a crosspiece against the lower end of the test block. This crosspiece may simply bear against the end of the test block as a pusher. If the test block is attached to the crosspiece by one or more screws or locating buttons, it will be held against the fence and reversal of the direction of feed will be possible. Provision for moving the holder crosswise is desirable for shifting the stock to center the cutting path, or for use when multiple cutting paths across the thickness of the specimen are required.

## Conclusion

The establishment of a standard technique for evaluating the cutting characteristics of wood is a worthy objective that should be reached as promptly as possible, but only with the assurance that specified technique is, first, based on a sound knowledge of the unique cutting conditions presented by wood and, second, that it will meet the present and future needs of both science and industry.

An immediate start on a provisional flexible standard is consistent with present knowledge. The establishment of such a standard will stimulate checks, tests, and a critical analysis that will hasten the establishment of a permanent standard technique that will apply not only to the test procedure itself, but also to essential features of the dynamometers used.

# Company Planning

## IN THE 1960'S

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Stanford Research Institute
Menlo Park, California

Chart 1

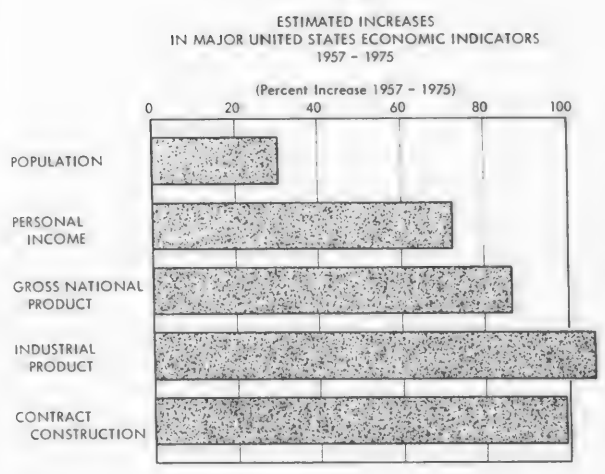
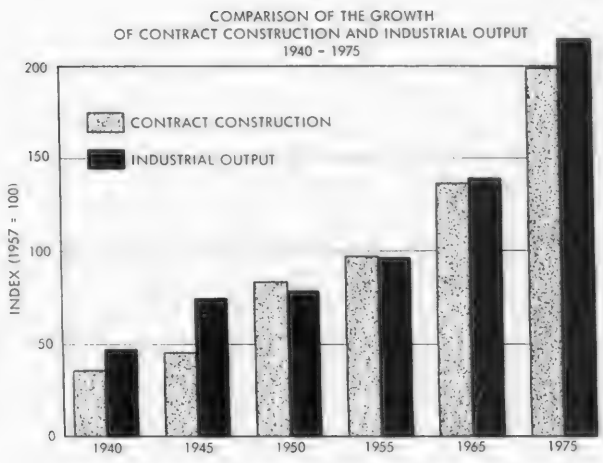



Chart 2




THE FOREST PRODUCTS INDUSTRY, with its investment in tree farms, has always been a leader for advance planning in industry. As far as raw materials are concerned, this industry has placed its bets on the long-term future, but what is it doing to insure a long-term market for its products?

In 1958, lumber and wood products companies as a group sold $3.3 billion worth of manufactured products. Pulp and paper accounted for an additional $10.3 billion. The United States total for all manufacturers was $305 billion. Thus, manufacturing based on forest products was about 5 percent of the total. This is about the same proportion of the sales of manufacturing corporations experienced by this industry for the past 10 years. At this juncture, the industry must ponder whether this position can be maintained or improved—or whether there is the possibility of a decline. What happens in the future will depend in good part on the effectiveness of planning to meet changing market conditions.

Planning certainly will not be the nswer to all of the industry's problems, but it can provide a basic road map and a sense of direction required for competitive success. All facets of corporate planning—sales, manufacturing, finance, product development, and research—can be used by aggressive and alert companies to protect their future market position.

**According to a recently completed study by the Stanford Research Institute, the most successful companies seemed to be aware of change, to visualize its impact on their business, and to place their companies in a position to take advantage of it.**

### Stanford Study

The results of a study by Stanford Research Institute on the growth of 400 United States corporations have demonstrated the tremendous importance of careful planning as a major factor in a long-term growth and profits of a business.

Some 4 years ago the Institute set out to try to find answers to the questions of how and why companies grow. To date, no full answers have been found; perhaps complete answers are unattainable. However, significant data were derived which can be used by practical businessmen to improve the long-term outlook for their companies.

### Method

First, a bit about the method for developing these data. Economists studied 210 companies which increased sales by 400 percent or more between 1939 and 1949. They also studied 169 companies which increased sales by 100 percent or less. The objective of the study was to find the factors accounting for this difference. Was it the industry they were in? Was it exceptionally good management? Was it better research? Was it better financing? Was it just luck?

According to the study, the most important single contribution to success appeared to be an awareness of change—a recognition of "what's new." Additionally, the most successful companies seemed to be able to visualize the impact of the change on their own business, and to place their

[1] Presented at the Wood Industries Conference, Portland, Oregon., September, 1959. Received November, 1959.

Chart 3

PERSONAL EXPENDITURE FOR HOUSING
AS A PERCENT OF TOTAL PERSONAL CONSUMPTION EXPENDITURES
1948 - 1958

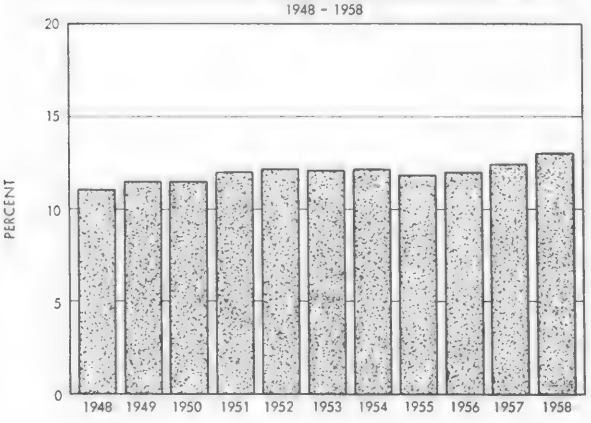
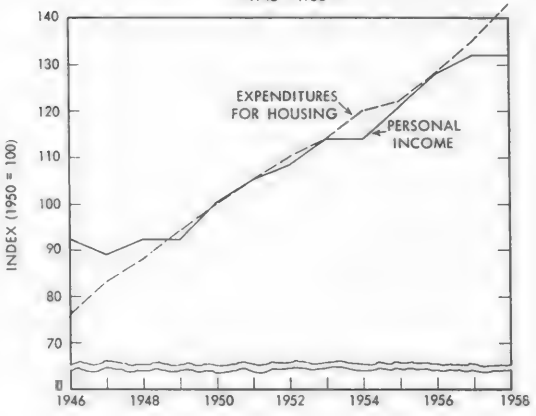



Chart 4

COMPARISON OF TOTAL PERSONAL INCOME
AND PERSONAL CONSUMPTION EXPENDITURES FOR HOUSING
1946 - 1958




companies in a position to take advantage of it.

How do companies recognize change? The ones that grow most robustly organize for change by supporting long-term future growth programs such as 1) Long-range company planning; 2) Product research and development; 3) Market research; 4) Diversification into other product fields and markets; 5) Acquisition of other organizations.

Merely instituting and following these practices will not automatically insure growth. However, the Institute's study indicated that a high percentage of the successful companies were following these practices and a high percentage of the unsuccessful ones were not.

Of this five-point program for long-term future growth, the coordinating one seems to be forward-planning. If careful forward-planning is present, the other success factors usually appear.

A valid question at this point could be: Isn't this all an academic exercise? It can be, and often is. It certainly will be in an organization where planning is not considered a function of the top level of management, including the board of directors. The study of company growth indicated that for the 116 most rapidly growing companies with formal planning efforts, 97—or more than 83 percent of the total—performed significant policy planning at the corporate officer level.

### Changes at Policy Level

What kind of change must be planned for at the policy level? Change in output, in marketing methods, in financing, and in competitive position. For example, some of the significant changes which apply to the forest products industry are discussed below.

Chart 1 is a graphic presentation of estimates of selected economic indicators for the next 15 to 20 years. These are population, personal income, gross national product, industrial production, and contract construction. By 1975 it is anticipated that population will be up 30 percent, personal income up 70 percent, gross national product up 85 percent, industrial production up 105 percent, and contract construction up 100 percent.

Each of these changes is significant in itself, and taken together, they indicate a strong upward movement over the long term for the economy as a whole. They may, however, have little specific effect on individual businesses because their totals are made up of many separate components moving both up and down with respect to the over-all trend. The movements of these specific components are usually the factors which can spell opportunity or disaster for individual companies regardless of the general trend.

Some of the changes in the components of each of these major indicators seem significant to the forest products industry. Look at population, for example. In 1958, we had 174 million people; by 1965, we expect to have 191 million; and by 1975, we expect to have 220 million. More important to the forest products industry than the sheer numbers are shifts in the composition of the population. For example, shifts are occurring in age group distribution, in geographical distribution, and in the income level of the age groups.

### Increased Teenage Population

Of particular interest is the rapid rise in the number of teenage children. In the next 10 years the number of teenagers in our population will rise 44 percent, or from 16.1 million to 23.3 million. The impact of the increase of this group on family spending patterns for housing, durable goods, food, clothing and education is difficult to assess. But it will certainly cause some drastic shifts and changes in consumption patterns and therefore, in markets.

A case in point is the impact on school construction. This surge of teenage population will create the largest percentage increase in the demand for secondary schools that we have ever seen. In 1962, 1963, 1964, and 1965, annual enrollments in these grade levels will increase between 6 and 10 percent per year on a base of between 8 to 10 million students. Roughly translated, this increase in enrollments means some $20 billion worth of new school construction in the next 10 years. In making plans for the 1960's, management must ask whether present products, product development organizations, and marketing operations are set up to take advantage of and maintain their competitive position.

Chart 2 compares the growth of contract construction and industrial output for the period 1940 to 1975. This is given in index numbers to show relative growth. A doubling of this segment of our national economy is shown as occurring within the next 10 years. The question confronting the timber industry would seem to be "Will we maintain our present position—or can we improve our position in construction by new product development in the future?"

### Residential Housing

Another vital part of the construction industry is residential housing. What changes are occurring in this market which will affect the lumber industry? In 1957, some 875,000 houses were started in the United

States. By 1965, estimates of 1,300,000 starts appear reasonable, as do 1,600,000 starts by 1970. A major change occurring in this market is the increased use of prefabricated housing—the assembly of factory-made parts at the site. Ten years ago only one of every 20 nonfarm, single family houses started in the United States was factory built. By 1957, one out of 10 was factory built. By 1965, it is estimated that one out of five houses will be factory built. From the standpoint of the planner, the product developer, and the marketer, the most single important impact of this change appears to be that it will be easier for competitive materials to be introduced into the housing industry than heretofore.

Another chart of general economic interest (Chart 3) compares personal income and expenditures for housing from 1948 to 1958. This shows that housing as a consumer budget expenditure maintains a fairly consistent position in relation to total personal income. In other words, as personal income grows, people apparently are willing to spend more money, on an absolute basis, for housing needs. Chart 4 shows the growth of expenditures for housing and personal income from 1946 to 1958.

### Competing Products

Another significant change for the 1960's is the increasing impact of competing materials on the markets for forest products. The forest products and allied industries have spent considerable sums on the improvement and development of products throughout the years. But, at the same time, others interested in the same market have also been spending considerably on research, and there is little evidence of a slackening. Competition from new products created in the laboratories outside the forest product industry can be expected to increase. This competition will be in terms of quantity, quality, and price. An illustration is the invasion of plastics into markets traditionally held by forest products. For example, plastic films may well replace wax paper in such uses as bread wrapping, where they can be competitive in price and provide a more attractive package.

Another example of the invasion of traditional markets is the use of reinforced plastics in boats. In 1958, it is estimated that nearly 40 million pounds of reinforced plastics were used in the manufacture of boats. In 1959, some 120 thousand glass-fiber-reinforced boat hulls were produced in what formerly was an exclusive market for wood.

It certainly is not going to be easy to increase the market for forest products, but progress can and will be made. The forest products industry will need to use every new tool at hand, and long-range plannning is a vital tool.

### Let's Not Wait For Defeat

To summarize, two points should be emphasized: (1) awareness of change is an essential for continued growth, and (2) long-range planning is the most effective tool for anticipating change and for coping with the problems of change. Farsighted management will not wait passively for defeat by unforeseen competition but will anticipate change and capitalize on the opportunities it offers.

## EFFECT OF CERTAIN VARIABLES ON

# Strength of Glued End Joints[1]

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**Glued butt end joints in balsa were prepared with three glue viscosities and two surface preparations over a wide range of specific gravities. Up to a certain point, strength increased with increase in specific gravity. Also, the more open sawed surfaces produced stronger joints than sanded surfaces. Glue of a lower viscosity gave the highest strength. It was concluded that surface and glue viscosity have a limited effect on strength of butt end joints, but that the adhesive system restricts the ultimate strength in tension.**

IN RECENT YEARS THERE HAS BEEN an increasing interest in joining wood end to end. This has come about because of the continuing need for long material, which is difficult to obtain as a single piece, and the increasing interest in utilizing short pieces that formerly were regarded as waste.

In considering the possibilities for end-joining of wood, it is natural to consider the adhesives that have been used so successfully in extending wood in the width and thickness dimensions. The problem of extending wood in length is unique, however, because of the very different characteristics of the surfaces to be glued and the fact that a higher strength level must be realized to give a useful joint.

Numerous types of glued end joints have been tried with varying degrees of success. Scarf and finger joints have been devised and are generally used for production requirements. These joints are good, but are often difficult to align properly. Also, they are wasteful of material, particularly when they are used to join relatively short pieces, since they all require an overlap. Butt joints, which are certainly the simplest and most logical choice for end joints, have been tried with little success and generally have been abandoned without a thorough understanding as to the cause for their deficiencies. The purpose of this investigation is to define the role of selected variables in determining the strength in tension of butt end joints.

A literature search at the time this study (1)[2] was initiated produced few references that were directly applicable to the fundamental problems of end gluing. As the project was nearing completion, Suchsland (7) and Marian (5) published related studies. Otto Suchsland (7), in an investigation of the penetration of glue into wood on side and end grain,

[1] A 1959 Wood Award entry, submitted while the author was a graduate student at Penn State University

[2] Numbers in parentheses refer to the Literature Cited at the end of this paper.

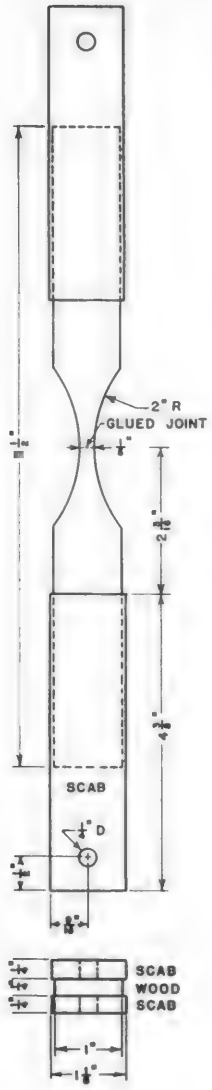


Fig. 2.—Test specimen.

found that the depth of penetration in itself was not correlated to the strength of the joints, but was merely an indication of other variables such as the condition of the surface and the gluing pressure. Marian and his co-workers (2, 5) found that the best end joints they could produce in assemblies that included both spring- and summerwood gave only about 12 percent of the strength of solid wood. These joints were formed with surfaces prepared by means of a microtome, and thus were considered indicative of what is to be expected with ideal surfaces. Marian also found that the strength of the joints remained constant over a specific gravity range from 0.20 to 0.65. On this basis, he concluded that the glue rather than surface preparation of porosity was the limiting factor in end-joint strength.

## Procedure

**Experimental Design:** There are a number of variables that might affect the strength of glued butt end joints; however, it was necessary to limit this experiment to those from which it was felt the most information could be gained. The variables chosen were glue viscosity, surface preparation, and specific gravity of the wood.

The adhesive used throughout was a resorcinol resin, Kopper's G–1131, which was selected because it is known to produce consistently good joints in wood, it can be cured at room temperatures, and because of color is easily detected under the microscope. This glue was used at three viscosity levels. The mixture of 100 parts by weight of liquid resin and 20 parts by weight of powdered catalyst, as recommended by the manufacturer was used as the middle or normal viscosity. The low viscosity was obtained by adding 15 parts of water to the above mixture, while the high viscosity was obtained by adding 20 parts of walnut-shell flour.

Tests were made on surface preparations obtained by sanding and sawing. These are two of the most common surfaces encountered in wood working. The sanded surface was produced by a fine-grain, 8-inch tungsten carbide abrasive wheel, and the sawed surfaces was generated with an 8-inch flat-ground cross-cut blade with 4 teeth to the inch.

Balsa wood (*Ochroma lagopus* Sw.) was selected as the wood to be used because it possesses two unique and useful characteristics. Of the greatest importance is the fact that balsa wood occurs naturally over a wide range of specific gravities. It is commercially available in densities of 4 to 18 pounds per cubic foot (4). This allowed the specific gravity to be varied without resorting to the change in species that is usually necessary in experiments involving an extended range of specific gravities. Also of importance is the homogeneity of balsa. It is a tropical wood; hence, it does not exhibit the growth zones of springwood and summerwood associated with woods grown in a temperate climate.

The specific gravity variable was broken down into six classes. Each was represented by a block taken at random, as far as specific gravity is concerned, from a density range designated by the supplier of the raw material (Table 1).

Table 1.—SPECIFIC GRAVITY CLASSES

| Specific gravity class | Supplier's density range | Specific gravity range |
|---|---|---|
| A | 4– 6 lbs./ft.³ | 0.064–0.096 |
| B | 6– 9 lbs./ft.³ | .096– .144 |
| C | 9–12 lbs./ft.³ | .144– .192 |
| D | 12–14 lbs./ft.³ | .192– .224 |
| E | 14–16 lbs./ft.³ | .224– .256 |
| F | 16–18 lbs. ft.³ | .256– .288 |

The three variables of surface preparation, glue viscosity, and specific gravity of the wood were tested in all

| | $S_1$ | | | $S_2$ | | |
|---|---|---|---|---|---|---|
| | L | N | H | L | N | H |
| A | | | | | | |
| B | | | | | | |
| C | | | | | | |
| D | | | | | | |
| E | | | | | | |
| F | | | | | | |

SURFACE
$S_1$ = SANDED
$S_2$ = SAWED

SPECIFIC GRAVITY
A = 064 – 096
B = 096 – 144
C = 144 – 192
D = 192 – 224
E = 224 – 256
F = 256 – 288

GLUE VISCOSITY
L = LOW
N = NORMAL
H = HIGH

Fig. 1.—Experimental design.

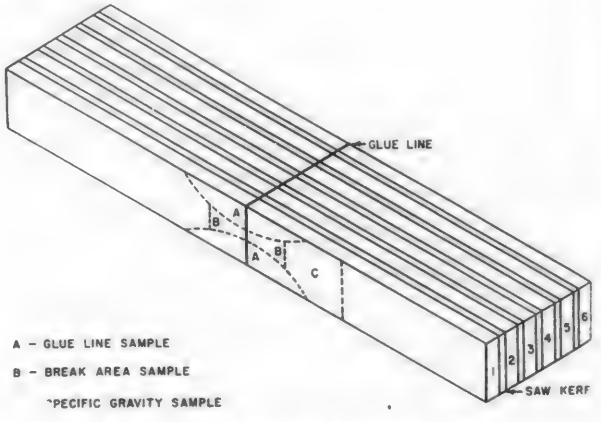


Fig. 3.—Glued balsa block showing method of cutting six test specimens.

combinations as shown in Fig. 1. Each combination was represented by six specimens cut from the same glued block.

**Test Specimen:** For this study it was necessary to select a tension-test specimen that could be manufactured with relative ease and still give the desired information. The standard specimen for testing solid wood in tension parallel to the grain was too large, and was difficult to handle and produce with the fragile glue joint in the center.

Hill (3) devised a specimen that he used to test balsa wood in tension along the grain. It was found that a similar type of specimen could be adapted to this study. Since the strength of specimens containing glued joints falls far below the strength of solid wood, it was felt that it might not be necessary to reinforce the grip area. When the available grips were applied directly to the wood, however, considerable crushing took place. The final design used is shown in Fig. 2. The specimen was held in the testing machine by means of a steel peg extending through two ¼-inch hardboard scabs and a metal plate that was located between them.

**Specimen Preparation:** Although the wood for each specific gravity class was selected at random, the material from which the final selections were made was carefully chosen for straight grain and freedom from defects. Prior to being glued, it was conditioned to a moisture content of 9 percent.

The wood that was 1¼ inches by 3¾ inches in cross-sectional area was cut into blocks 4¾ inch long with either the sanding disk or saw blade, depending upon which surface was desired. Two blocks cut from the same piece were turned end for end and glued immediately following the cutting operation. The turning was done to eliminate any effect that surface matching might have upon the strength of the glued joints.

The glue was measured onto the wood and spread on both faces. In all cases, the amount of glue applied was 3 milliliters. This was sufficient to cause a liberal squeeze-out even when the highest glue viscosity was used. Spreading was accomplished with a spatula, and care was taken to avoid disturbing the surface characteristics through any rubbing action. The two blocks were then assembled and placed under pressure. The clamping device provided a constant pressure of 100 psi by means of a lever and weight arrangement. The blocks remained in the clamp at room temperature for a minimum of 8 hours.

The glued blocks were reconditioned to 9 percent moisture content and

**Table 2.—AVERAGE TENSILE STRENGTH, SPECIFIC GRAVITY, GLUE PENETRATION AND TYPE OF FAILURE FOR EACH TREATMENT**

| Treatment | Tensile Strength (psi) | Specific Gravity | Relative Glue Penetration | Percent of Each Type of Failure | | |
|---|---|---|---|---|---|---|
| | | | | Type I | Type II | Type III |
| $S_1LA$ | 1064 | .0992 | 116 | 35 | 65 | 0 |
| $S_1LB$ | 1586 | .1185 | 124 | 28 | 72 | 0 |
| $S_1LC$ | 1945 | .1858 | 158 | 67 | 33 | 0 |
| $S_1LD$ | 2025 | .1888 | 112 | 25 | 75 | 0 |
| $S_1LE$ | 1831 | .2358 | 144 | 87 | 13 | 0 |
| $S_1LF$ | 1729 | .2558 | 142 | 100 | 0 | 0 |
| $S_1NA$ | 1049 | .0831 | 117 | 7 | 12 | 81 |
| $S_1NB$ | 1748 | .1161 | 144 | 47 | 40 | 13 |
| $S_1NC$ | 1793 | .1755 | 142 | 99 | 0 | 1 |
| $S_1ND$ | 1571 | .1834 | 110 | 28 | 0 | 72 |
| $S_1NE$ | 1128 | .2037 | 104 | 100 | 0 | 0 |
| $S_1NF$ | 1476 | .2528 | 96 | 100 | 0 | 0 |
| $S_1HA$ | 1222 | .0835 | 108 | 25 | 3 | 72 |
| $S_1HB$ | 1558 | .1401 | 92 | 87 | 8 | 5 |
| $S_1HC$ | 2150 | .1822 | 81 | 37 | 63 | 0 |
| $S_1HD$ | 1106 | .1977 | 90 | 77 | 17 | 6 |
| $S_1HE$ | 1059 | .2252 | 60 | 83 | 17 | 0 |
| $S_1HF$ | 991 | .2585 | 62 | 100 | 0 | 0 |
| $S_2LA$ | 928 | .0968 | 137 | 0 | 85 | 15 |
| $S_2LB$ | 1793 | .1401 | 197 | 37 | 63 | 0 |
| $S_2LC$ | 1860 | .1363 | 158 | 5 | 95 | 0 |
| $S_2LD$ | 2038 | .1877 | 154 | 35 | 65 | 0 |
| $S_2LE$ | 2008 | .2238 | 184 | 83 | 17 | 0 |
| $S_2LF$ | 2127 | .2606 | 160 | 100 | 0 | 0 |
| $S_2NA$ | 1394 | .0857 | 174 | 0 | 0 | 100 |
| $S_2NB$ | 1792 | .1215 | 188 | 80 | 0 | 20 |
| $S_2NC$ | 1930 | .1748 | 108 | 80 | 3 | 17 |
| $S_2ND$ | 2364 | .1819 | 154 | 92 | 8 | 0 |
| $S_2NE$ | 2653 | .2166 | 158 | 90 | 10 | 0 |
| $S_2NF$ | 2177 | .2766 | 147 | 100 | 0 | 0 |
| $S_2HA$ | 1275 | .0927 | 92 | 33 | 28 | 39 |
| $S_2HB$ | 1470 | .1196 | 145 | 42 | 10 | 48 |
| $S_2HC$ | 1590 | .1595 | 124 | 45 | 55 | 0 |
| $S_2HD$ | 1993 | .2000 | 94 | 33 | 67 | 0 |
| $S_2HE$ | 1870 | .2375 | 132 | 67 | 33 | 0 |
| $S_2HF$ | 1499 | .2792 | 89 | 100 | 0 | 0 |

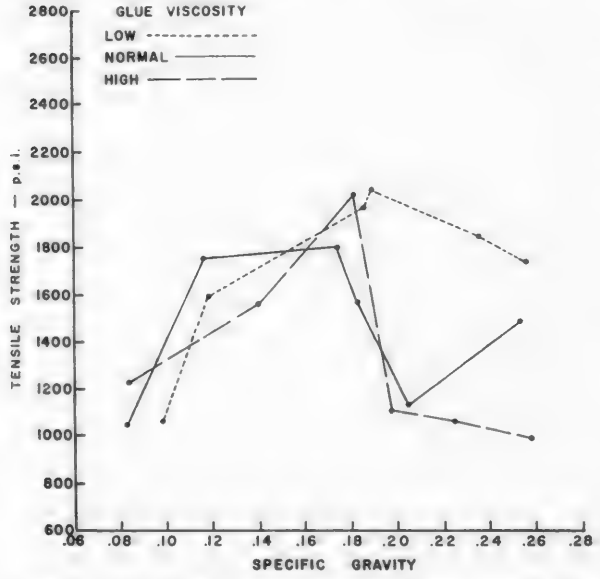


Fig. 4a.—Experimental results showing the relationship of tensile strength to specific gravity for three glue viscosities on the sanded surface.

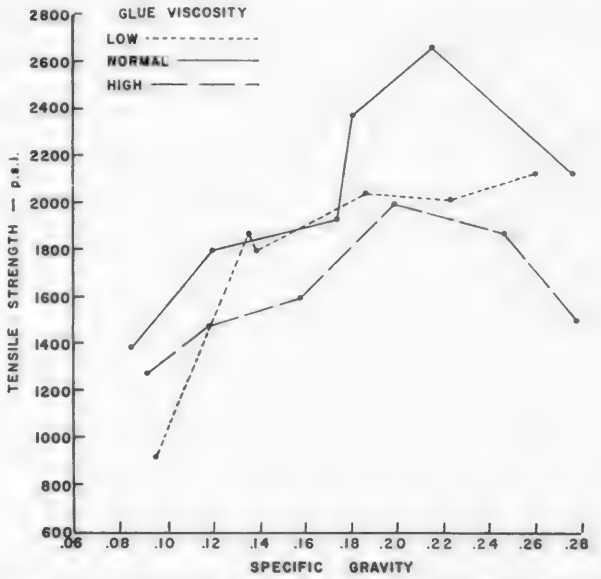


Fig. 4b.—Experimental results showing the relationship of tensile strength to specific gravity for three glue viscosities on the sawed surface.

Table 3.—ANALYSIS OF REGRESSION OF TENSILE STRENGTH ON SPECIFIC GRAVITY FOR THE COMBINED DATA

| Source of Variation | Sum of squares | Degrees of freedom | Mean square | F ratio |
|---|---|---|---|---|
| Total | 262,895 | 30 | | |
| Regression | 111,131 | 2 | 55,565 | 10.25**[1] |
| Error | 151,764 | 28 | 5,420 | |

[1]**significant at the 1 percent level.

Table 4.—ANALYSIS OF REGRESSION OF TENSILE STRENGTH OF SPECIFIC GRAVITY FOR SANDED AND SAWED SURFACES AND DIFFERENCES BETWEEN REGRESSIONS

| Surface | Regression | | | Error of estimate | | | F ratio for regressions |
|---|---|---|---|---|---|---|---|
| | Sum of squares | Degrees of freedom | Mean square | Sum of squares | Degrees of freedom | Mean square | |
| Sanded | 41,887 | 2 | 20,944 | 81,904 | 13 | 6,300 | 3.32 |
| Sawed | 108,061 | 2 | 54,030 | 31,043 | 13 | 2,388 | 22.62**[1] |
| Sum of sanded and sawed | 149,948 | 4 | ------ | 112,947 | 26 | 4,344 | |
| Composite within sanded and sawed | 111,131 | 2 | ------ | 151,764 | 28 | ------ | |
| Difference between regressions | 38,817 | 2 | 19,408 | 38,817 | 2 | 19,408 | 4.47* |

[1]**Significant at the 1 percent level.
*Significant at the 5 percent level.

planed on both surfaces to a thickness of one inch. One edge was then jointed and six specimen blanks were cut from each as shown in Fig. 3. The narrowed part, or neck, of the individual specimen was cut out, and pieces that were removed were saved for microscopic examination of the glue lines.

**Testing:** Prior to the testing, the cross-sectional area of each glue line was determined. The specimen was then tested in tension at a speed of 0.05 inches per minute, and the tensile strength was calculated in pounds per square inch.

After the specimen was tested, the area at which the break occurred was cut from the rest of the specimen and saved for microscopic examination. The area immediately adjacent to this on one side of the break was used for a specific gravity sample. The specific gravity samples were oven dried, weighed, and their volume determined by mercury displacement.

**Microscopic Observations:** The glue-line samples lateral to the neck were examined by smoothing off the inner surfaces with a razor and placing both pieces next to each other on the stage of a microscope equipped for observation with reflected light at a magnification of 36x. A point of observation was selected at random some place along the entire glue line, and a sketch was made of the glue penetration into the wood. This was done by using a 10-unit square grid recticle in the eyepieces of the microscope and sketching what appeared in each grid of the recticle in a ¼-inch square on crossection paper. From the glue-line sketch, the relative glue penetration was determined by placing a dot grid of 64 dots to the inch over the sketch and counting all dots that fell in the area of glue. Dots falling on border lines were alternately counted. The number of dots was used to indicate the relative penertation. This method describes the total penetration and not the depth of penetration. The former was believed to be more closely related to joint strength than the depth of penetration. On some specimens the depth of penetration was considerable, particularly where the adhesive entered and followed the vessels.

Microscopic observation also was made on the failures obtained with each specimen. These were classified and an estimate was made of the percentage of each that occurred. Three types were distinguished. They may be described as follows.

Type 1—at the glue line.
Type 2—in wood that was saturated with glue.
Type 3—in wood not containing glue.

Where they could be distinguished, failures immediately adjacent to the wood accounted for 80 to 90 percent of the Type 1 group. No attempt was made to tabulate this as a subgroup in the final results. The Type 2 failures could be recognized easily by the presence of elements of wood that remained visible even in areas heavily saturated with adhesive.

## Results and Analysis

The average results for the six replications for each treatment are given in Table 2. Although each combination of surface treatment and viscosity contains six specific gravity classes of approximately the same levels, these classes do not have numerically equal average specific gravities. Because of this, it was not possible to make a direct comparison of the different treatments. Since specific gravity can be treated as a continuous variable across the six specific-gravity classes, a covariance method of analysis was selected. It is apparent from the graphic representation of the data in Fig. 4 that the relationship of strength to specific gravity is not linear. This made it necessary to introduce a quadratic term into the analysis in the form of the square of the specific gravity. It was then necessary to use the methods of multiple covariance (6).

To test the overall significance of the tensile strength—specific gravity relationship, all of the data, regardless of surface preparation or glue viscosity, were combined. An analysis of the covariance as shown in Table 3 indicates that there is a significant relationship of the form

$$Y = a \pm bx + cx^2$$

between the tensile strength (Y) and the specific gravity (x). The necessary coefficients were determined, and the curve was drawn as shown in Fig. 5.

Since the relationship between specific gravity and tensile strength was significant, it was felt that all tests of significance for differences due to surface preparation and glue viscosities should be made with reference to regressions on specific gravity.

To determine the effect of surface preparation, the regression for each surface independent of glue viscosity was computed, and a comparison was made as shown in Table 4. Although the sanded-surface regression was not significant in itself, it was still possible to test it against the sawed-surface regression. This test indicated a significant difference at the 5 percent level. The effects of the two surfaces and specific gravity may be seen in Fig. 6.

The three glue viscosities independent of surface preparation were examined next. The results of this test are summarized in Table 5. Only the lowest viscosity produced a curve that

Table 5.—ANALYSIS OF REGRESSION OF TENSILE STRENGTH OF SPECIFIC GRAVITY FOR THREE GLUE VISCOSITIES AND DIFFERENCES AMONG REGRESSIONS

| Glue viscosity | Regression | | | Error of estimate | | | F ratio for regression |
|---|---|---|---|---|---|---|---|
| | Sum of squares | Degrees of freedom | Mean square | Sum of squares | Degrees of freedom | Mean square | |
| Low | 84,952 | 2 | 42,476 | 9,443 | 8 | 1,180 | 36.00**[1] |
| Normal | 33,303 | 2 | 16,652 | 55,169 | 8 | 6,896 | 2.41 |
| High | 27,601 | 2 | 13,800 | 52,428 | 8 | 6,554 | 2.11 |
| Sum of three viscosities | 145,856 | 6 | | 117,040 | 24 | 4,877 | |
| Composite within three viscosities | 111,131 | 2 | ------ | 151,764 | 28 | ------ | |
| Difference among regressions | 34,725 | 4 | 8,681 | 34,724 | 4 | 8,681 | 1.78 |

[1]**Significant at the 1 percent level.

Table 6.—ANALYSIS OF REGRESSION OF TENSILE STRENGTH ON SPECIFIC GRAVITY FOR THREE GLUE VISCOSITIES ON THE SAWED SURFACE AND DIFFERENCES AMONG REGRESSIONS

| Glue viscosity | Regression | | | Error of estimate | | | F ratio for regressions |
|---|---|---|---|---|---|---|---|
| | Sum of squares | Degrees of freedom | Mean square | Sum of squares | Degrees of freedom | Mean square | |
| Low | 55,813 | 2 | 27,906 | 2,499 | 3 | 833 | 33.50**[1] |
| Normal | 44,596 | 2 | 22,298 | 14,586 | 3 | 4,862 | 4.59 |
| High | 18,876 | 2 | 9,438 | 2,734 | 3 | 911 | 10.36* |
| Sum of three viscosities | 119,285 | 6 | | 19,819 | 9 | 2,202 | |
| Composite within three viscosities | 108,061 | 2 | | 31,043 | 13 | | |
| Differences among regressions | 11,224 | 4 | 2,806 | 11,224 | 4 | 2,806 | 1.27 |

[1] **Significant at the 1 percent level.
*Significant at the 5 percent level.

showed a significant relationship between specific gravity and tensile strength (See Fig. 7). However, the regressions were not significantly different for the three viscosity groups.

Since the first-order interaction of specific gravity and glue viscosity showed no significant differences, there appeared to be little reason to test the second-order interactions including both surface and glue viscosity. Since the sawed surface produced a highly significant regression, however, a test was made of the three glue viscosities on this surface. This test is summarized in Table 6. The difference among the regressions is not significant, but the high- and low-viscosity regressions were both significant in themselves. Because of this, it was felt that a test between these extremes might give a general indication of the glue viscosity effect. The regressions were tested as shown in Table 7 and plotted in Fig. 8. At this point, there seemed to be little more that could be learned from the data by these methods, regardless of what combinations were made.

In summary, the statistical evaluation has shown that: (1) regardless of treatment the tensile strength of the joint is related in a quadratic manner to the specific gravity; (2) separation of the data for the two surfaces showed that the regressions were significantly different but that a significant relationship between tensile strength and specific gravity held for the sawed surface only; (3) in a test of all three glue viscosities independent of surface preparation, only the low glue viscosity gave a significant curve; (4) a further separation of the data for the sawed surface showed that the strength—specific gravity relationship held for the low and high glue viscosities; (5) a test between these regressions showed that they were significantly different.

The values obtained for the relative penetration did not lend themselves to any type of statistical evaluation; however, certain trends should be noted. There was no change in the degree of penetration for different specific gravities except on the sanded surface with the high glue viscosity. Here an increase in specific gravity produced a decrease in penetration. The penetration of the two surfaces was somewhat different. It was observed that there was less penetration on the sanded surface than on the sawed surface. In comparing the penetration of different glue viscosities, the only general difference was a shallower penetration by the highly viscous glue.

Evaluation of the types of failures also showed some interesting trends that were correlated with specific gravity. At the lowest specific gravity, there were mostly Type 2 and Type 3 breaks. The occurrence of these types became less frequent with increasing specific gravity until at the highest specific gravity, only Type 1 breaks were observed. Type 1 was by far the most frequently occurring failure found at all specific gravity levels. The only difference in types of failures between the two surfaces was that the sanded surface had more Type 1 failures. There did not appear to be any distinguishable difference in the trend of failure types among the glue viscosities.

## Discussion

The most important item of interest in any type of joint is the ultimate strength of the assembly. Ideally, this is limited by the material itself and not the joint it contains. It is obvious from this study that the full tensile strength of balsa cannot be produced over the complete specific gravity range. At a specific gravity of 0.08, however, the strength of the joint assemblies is very close to the value of 1200 psi reported by Hill (3). It appears that the wood and not the glue joint is the limiting factor. Most failures occur in the wood, with only a few occurring at the glue line. This indicates that all but the very poorest

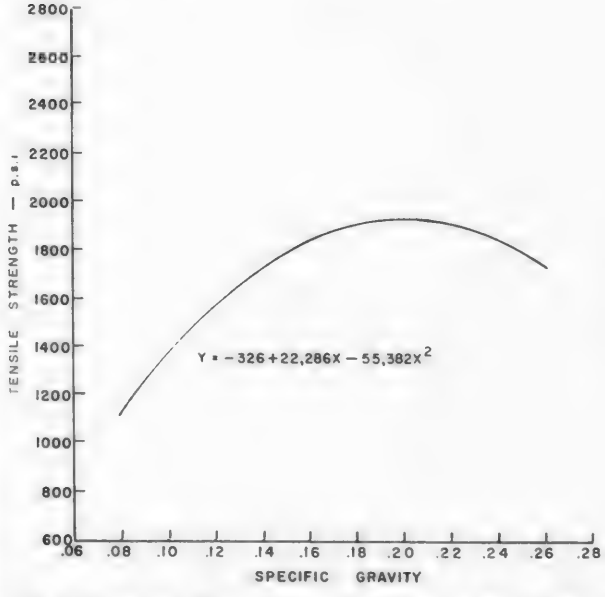


Fig. 5.—Regression of tensile strength on specific gravity for the combined data.

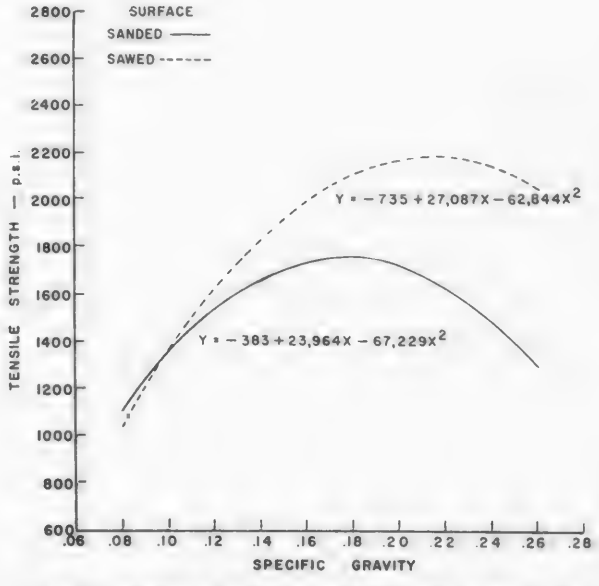


Fig. 6.—Regression of tensile strength on specific gravity for sanded and sawed surfaces.

Table 7.—ANALYSIS OF THE DIFFERENCE BETWEEN THE REGRESSION OF TENSILE STRENGTH ON SPECIFIC GRAVITY FOR THE LOW AND HIGH GLUE VISCOSITIES ON THE SAWED SURFACE

| Glue viscosity | Regression | | | Error of estimate | | | F ratio for regressions |
|---|---|---|---|---|---|---|---|
| | Sum of squares | Degrees of freedom | Mean square | Sum of squares | Degrees of freedom | Mean square | |
| Sum of low and high | 74,689 | 4 | | 5,233 | 6 | 872 | |
| Composite with low and high viscosities | 65,377 | 2 | ----- | 14,545 | 8 | ----- | |
| Difference between regressions | 9,312 | 2 | 4,656 | 9,312 | 2 | 4,656 | 5.34*[1] |

[1]*Significant at the 5 percent level.

of joints can reproduce the tensile strength of the wood in this specific gravity class. As the specific gravity increases, the strength of the solid wood increases without a corresponding increase in joint strength. For example, at a specific gravity of 0.12, Hill reports a solid wood strength of approximately 2900 psi while the best obtained in this study with a glued specimen of like density was only 1600 psi.

Inspection will show that the general appearance of all the strength curves, regardless of treatment, is very much the same. All of the curves show strength values at the lowest specific gravity which are very nearly equal. From this point, the curves rise at varying slopes and reach a maximum strength value between specific gravities of 0.18 and 0.22. Variations in the slope of the rising part of the curve and in the strength level at which the maximum occurs may be wholly or partially attributable to factors such as the surface and glue viscosity. It should be possible to find a combination of treatment factors that will very nearly approach the strength of solid wood on the rising part of the curve and give a higher maximum than was obtained in this study.

Although only two surfaces were tested, they are sufficiently different to give a general indication of surface effect. In Fig. 9, it is evident that the sawed surface has a considerable number of exposed vessel and fiber ends, while practically none are observable on the sanded surface. Although both treatments result in the fibers being bent over at the surface, sanding causes bending to a greater extent than does sawing, since the latter results in a portion of the fibers being cut off cleanly. The more open sawed face gives the glue a better chance to make good contact with the undamaged wood and to reinforce damaged fibers.

Joints prepared with a sawed surface showed the greatest total glue penetration. Since there was no overall correlation between penetration and strength or penetration and specific gravity, it appears that the differences in penetration are important only as an indication of the ability of the glue to reach an undamaged open surface. This leads to a consideration of why the amount of glue penetration was independent of the specific gravity. If the more open sawed surface shows a greater penetration than the sanded surface, it would seem logical to expect a greater penetration in the low specific gravity joints, which have available a greater void space. There may be several reasons why this does not occur. Regardless of specific gravity, the surface may limit the amount of penetration, or it may be that the volume of glue available for penetration is limiting. Still a third possibilty is that there is ample pore space even in wood with the highest specific gravity to permit sufficiently good penetration if an undamaged surface is exposed.

Several low-strength specimens showed a complete lack of penetration The resulting failures were at the junction of the glue line and the wood with limited fiber pull. This shows that it is necessary to have some penetration in order to insure good wetting and to strengthen the damaged fibers. Increased penetration over this amount does not result in strength increases.

The glue viscosity effect seems to be directly related to the problem of wetting and fiber reinforcement. It was shown that the high-viscosity glue resulted in a lower joint strength than did a glue of less viscosity. The high viscosity gave generally less penetration, particularly on the sanded sur-

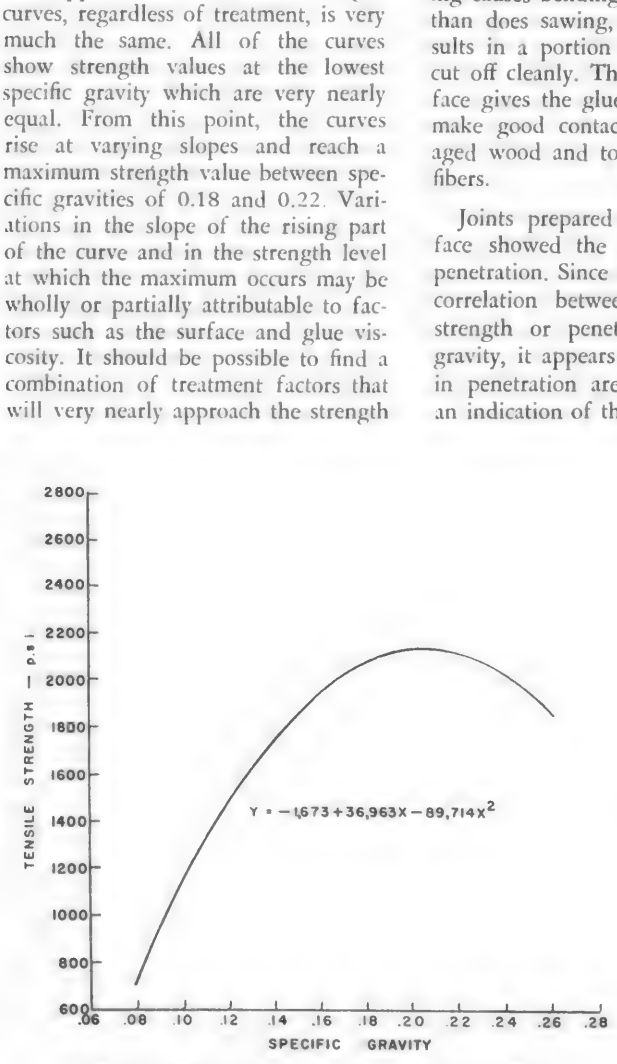


Fig. 7.—Regression of tensile strength on specific gravity for the low glue viscosity.

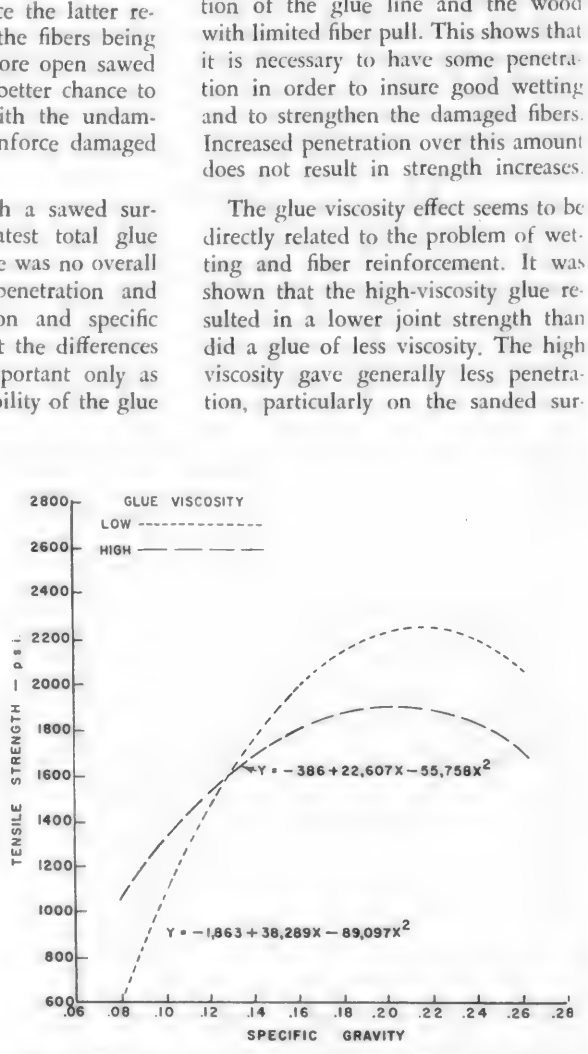


Fig. 8.—Regression of tensile strength on specific gravity for the high and low glue viscosities on the sawed surface.

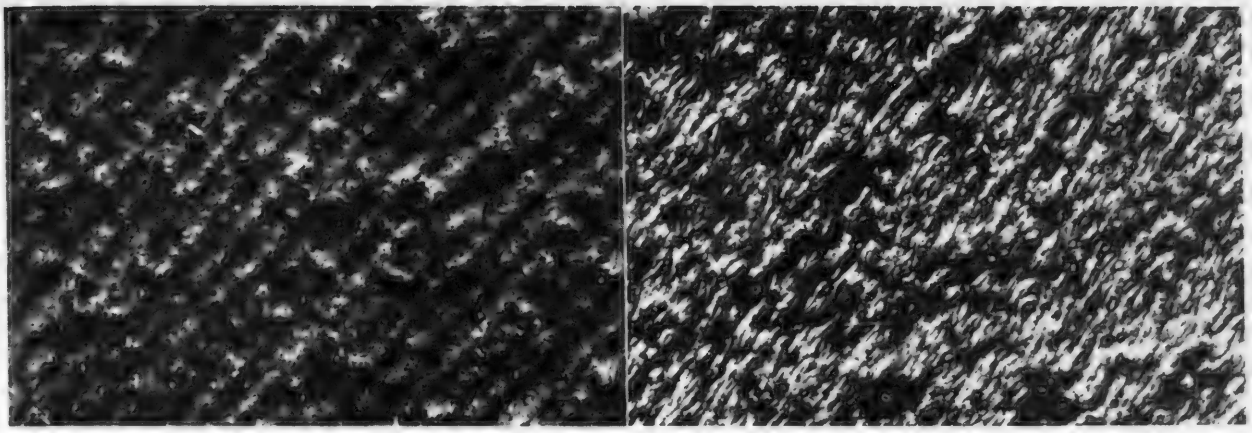

Fig. 9.—Enlarged views of typical end grain surfaces prepared by sawing (left) and sanding (right). The sawed surface is more open, with areas of undamaged wood clearly visible, particularly around the vessels. The sanded surface is closed, with nearly uniform bent fiber ends.

face. The combination of a sanded surface and high glue viscosity produced low joint strength with most failures occurring at the glue line. Under similar conditions, the sawed surface showed better penetration, but joint strength appeared to be limited by poor wetting from the very viscous glue. Still another factor that may limit the strength of these joints is the relatively thick glue lines that are developed with the high-viscosity glue. Glue of low viscosity showed good joint strength with both surfaces. Here it is apparent that the penetration is enough, even on the closed sanded surface, to reach the undamaged surface and also to strengthen the fibers.

In all cases there appears to be a decrease in strength with an increase in specific gravity after the maximum strength has been reached. It is unlikely that the strength actually falls off to the degree that is represented by the curves obtained here. Certainly it is more logical to assume that the indicated decrease is the result of the use of a parabolic equation form to express the relationship between tensile strength and specific gravity. More likely, the tensile strength level remains constant with an increased specific gravity. This would be in accord with the findings of Marian (5), who showed that the tensile strength remained constant in the specific gravity range of 0.20 to 0.65.

Since there is no increase in joint strength with increases in specific gravity after a certain level has been attained, it is necessary to conclude that the adhesive system is itself limiting. Careful inspection of the failures shows that all failures at the highest specific gravity are Type 1, regardless of the amount of penetration. Furthermore, most failures occur in the glue next to the wood. This would indicate that the glue at this point is altered in such a way that it is weakened. It is not logical to say that the adhesive is too weak, because the same material will produce higher strength levels in scarf joints. The exact causes for failures in the adhesive at these low stress levels are beyond the scope of this study, but certainly warrant further investigation if a successful butt end joint is to be achieved.

## Conclusions

1. This study has shown that the tensile strength of glued butt end joints is affected by changes in specific gravity up to a specific gravity of approximately 0.20. Beyond this value, increases in specific gravity no longer give increases in strength. At the lowest specific gravity, most failures occurred in the wood, while at the highest specific gravity, all failures occurred at the glue line. Between these extremes, there was a general gradation from wood to glue-line failure. At this latter point, the adhesive system becomes limiting.

2. Of the two surfaces tested, the surface produced by sawing gives a better joint than does the sanded surface. Close inspection of the surfaces shows that the sawed surface is more open and does not have as great a number of bent fibers.

3. Examination of the effect of different glue viscosities on joint strength showed that glue of a high viscosity produced poorer joints than glue of a lower viscosity. This was particularly pronounced on the sanded surface.

4. In end gluing, penetration is required only to the extent necessary for the adhesives to reach an undamaged surface. In doing this it accomplishes a secondary purpose; namely, the reinforcement of the fibers damaged in preparing the joints.

5. Future progress in increasing the efficiency of butt end joints lies in developing a system that will permit the formation of a bond that is capable of developing a higher percentage of the full strength of both adhesives and adherend.

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## EFFECT OF REPEATED LOADING ON

# Tensile Properties of Wood[1,2]

Fig. 1.—Tensile testing instrument, with test chamber and tension specimen in position.

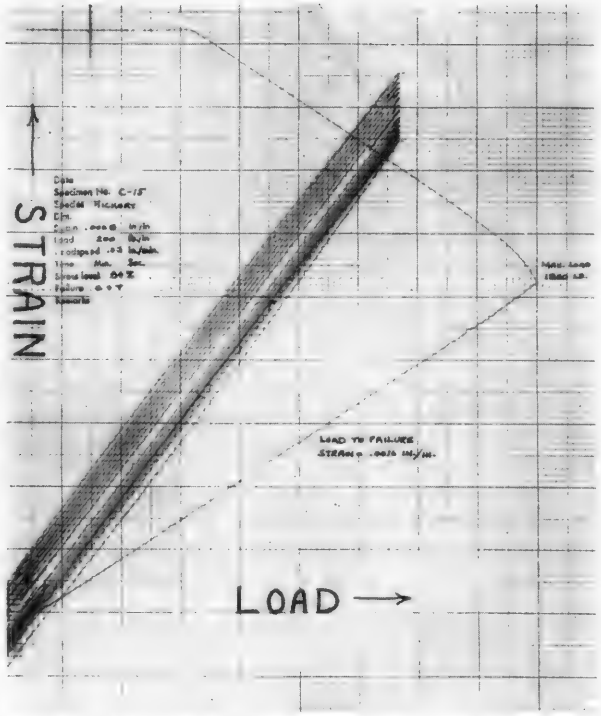


Fig. 2.—Example of a test record as produced by the recorder. Each line on the graph is a load-strain diagram for a different stress cycle. Only a few fixed-cycle numbers were recorded so that an adequate spacing was maintained between the points to be measured. The strain magnification on the final loading cycle was reduced by one-half.

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AN UNDERSTANDING OF THE BEhavior of wood under repeated loading conditions is important for several reasons. First, information of this kind contributes to a better understanding of the phenomenon of fatigue in wood, which may lead to a more enlightened approach to the use of wood under such conditions. Secondly, a better knowledge of the rheological behavior of wood—that is, its time-dependent behavior—is of fundamental scientific interest because of what it may reveal concerning molecular structure and configuration. Through the accumulation of information on the rheological behavior of wood under repeated loading, this particular study supplements other works, such as those based on sustained loading and vapor sorption techniques, in contributing to a better understanding of the molecular organization of the cell wall.

**Creep of wood under repeated loading in tension is primarily controlled by the initial strain. Ultimate tensile strain may increase after repetitive stressing due to creep that has occurred during cycling.**

Research studies on the rheology of cellulosic high polymers in the form of natural and synthetic fibers have been, in general, far more basic and comprehensive than those on wood, primarily because of their importance to a research-conscious textile industry. A brief review of the results of such work was presented in an earlier paper (8)[3].

A study of tensile stresses offers a most fruitful area in which to initiate work of this type. The strain behavior of wood under repeated loading in tension was selected for investigation not so much because of specific interest in tensile stress as such, but more because it is a pure stress and does not involve the complications of eccentricity which arise in applying compression loads or of the combined stresses that exist in bending.

Emphasis was placed on the description of the creep-initial strain relationship, with an effort made not merely to describe the behavior of individual species, but to clarify the basic rheological behavior of wood in general. For this reason, tests were conducted on nine species including both hardwoods and softwoods with diverse anatomical, physical, and mechanical properties. For example, the specific gravities of the species tested ranged from 0.25 for ceiba to 1.05 for kanehart. Each specimen was subjected

[1] Second-place winner in the 1960 Wood Award competition.

[2] This research is part of a comprehensive study being conducted at the Yale School of Forestry in cooperation with The Office of Naval Research, Dept. of Navy, under contract Nonr. 609(13), Project NR 330-001, Properties of Tropical Woods.

[3] (See p. 588)

100 cycles of loading to a fixed stress level. The stress levels investigated ranged from 30 to 80 percent of the ultimate tensile stress for each species.

The major part of this study is concerned with determinations of the magnitude of creep that occur during the cyclic stressing of air-dry wood. It is also concerned with the effect of repetitive stress cycles on the modulus of elasticity, ultimate tensile strength, and ultimate tensile strain.

## Test Procedure

The test procedures used in this study will be discussed in a somewhat abbreviated manner since they have already been described in an earlier paper (8) concerned with some of the exploratory results of this work.

Nine species of domestic or tropical origin were prepared for tests. The common and scientific names of these species as well as their specific gravity values are shown in Table 1. The standard tension-parallel-to-the-grain specimen as described in ASTM Designation 143–52 (3) was used in this study. These specimens were prepared from three planks from each species with the specimens from each plank being designated as a series. To facilitate closer matching of the test material within a plank, a special laminating procedure was used in the preparation of the specimen blanks. Material that exhibited a slope of grain steeper than 1 in 28 was discarded unless the particular species characteristically exhibited an interlocked grain. After final machining, the specimens were stored in a chamber at a temperature of 90° ± 1° F. and a nominal equilibrium moisture content of 12 percent. Humidity was maintained by means of a saturated sodium nitrite solution.

Strain was measured with SR–4 type AD–1 strain gages bonded on the ⅜-inch face at the center of the critical section. After the gages were wired, the entire critical section was covered with a light-weight polyvinyl plastic film to protect the gage against mechanical damage as well as to reduce any unintended change in moisture content. Compensating specimens were prepared with gages in an identical manner for all species. Each of these compensating specimens had the same cross-sectional dimensions as the critical section of the test specimen, and was rigidly held in a small wooden jig.

The tests were all conducted with a type TT-C-L Instron tensile testing instrument, shown in Fig. 1. Test conditions of 90 ± 1° F. and a relative vapor pressure equivalent to a nominal 12 percent moisture content were maintained in a specially built test chamber by means of a thermostatically controlled light bulb and a saturated sodium nitrite solution. This chamber, as well as the test specimen and compensating specimen, is shown in test position in Fig. 1.

Initially, 12 specimens for each species, 4 from each of the 3 series, were selected at random and loaded to failure at a cross-head speed of 0.03 inch per minute. A Baldwin model PS–5M microformer extensometer was used to determine the ultimate tensile strain for these control specimens. With the establishment of the ultimate tensile strength and strain for each series it was then possible to select the various fixed stress levels to which the other specimens in each series were to be loaded in a repetitive manner.

Eighteen specimens, 6 from each of the 3 series, were then selected at random for repetitive stressing. Three specimens, 1 from each series, were tested at each of the 6 stress levels: 30, 40, 50, 60, 70, and 80 percent of the average ultimate tensile strength of the controls. After a suitable gage warm-up period, the machine was adjusted to cycle between the selected load level and a lower load level that was less than 1 percent of the full-scale load. Strain sensitivity ranged from ± 3 to ± 8 microinches per inch, depending on the particular strain magnification employed. During the repeated loading cycle, the cross-head speed was maintained at 0.03 inch per minute. A record of the load-strain behavior was automatically recorded by the Instron XY recorder. This recorder is in the upper left hand panel of the tensile testing instrument shown in Fig. 1. An example of a test record made by this recorder is shown in Fig. 2. After 100 uninterrupted cycles of loading to the selected load level, each specimen was loaded to failure. Following this, slope of grain adjacent to the point of failure, as well as the moisture content and specific gravity of a small sample taken near this same point, was determined.

## Results

A summary of the test results is shown in Table 1. All values shown are average values for the species. The creep and initial strain values were obtained by determining the averages for each series at each of the assumed stress levels. The maximum strain values include the increase in deformation during the cyclic loading period as well as the strain at maximum load for the last cycle. The initial strain values shown are the strains at the assumed level of stress in the first loading cycle. Due to the natural variability of wood, the actual stress level expressed as the percentage of the ultimate tensile strength of each specimen varied somewhat from the assumed stress levels, which were based on the average tensile strength of the control specimens.

Creep is normally defined as a change in strain under a sustained load, but in this paper the term creep will be used to describe the change in strain which occurred at a fixed load level during the repeated loading. In analyzing the data it was determined that less variability was exhibited when creep was plotted against initial strain rather than against the originally selected independent variate, percentage of ultimate tensile stress. It was found that the creep-initial strain relationship could be represented by an exponential regression of the general type

$$\triangle e_1 = e^{(a + be_1)} - c$$

where $\triangle e_1$ = creep in microinches per inch; $e_1$ = initial strain, 1000 microinches per inch; $e$ = base of natural logarithms; and $a$, $b$, and $c$ are constants.

Creep-cycle number curves at fixed initial strain levels were constructed by obtaining the creep value from the fitted exponential regressions at the selected initial strains and plotting them over the cycle number. The creep-cycle number curves obtained in this manner were found to be satisfactorily described by a power equation of the general type

$$\triangle e_1 = a + N^b - c$$

where $\triangle e_1$ = creep, microinches per inch; $N$ = the cycle number; and $a$, $b$, and $c$ are constants. The value of the constant $c$ producing the best average linearity in both equations for all species was 60.

With the selection of the constant $c$, and a satisfactory description of both the creep-initial strain relationship and creep-cycle number relationship, it was possible to derive a joint function or plane relating creep to initial strain and cycle number for all species. The general equation developed for this plane is of the type

$$Y = b_1 X_1 + b_2 X_2$$

$$\text{where } Y = \log\left(\frac{\triangle e_1 + c}{c}\right);$$

$X_1 = e_1 \log N$; $X_2 = \log N$.

An IBM 650 computer was employed in fitting a plane to the data for each of the species. This involved entering the different values of Y, $X_1$, and $X_2$ for each specimen at the 10th, 20th, 50th, and 100th cycle on individual IBM cards. The computer was programmed to solve this multiple regress by means of a matrix analysis.[1]

[1] G. W. Snedecor (1956) Statistical Methods, Iowa State College, Ames.

Table 1.—SUMMARY OF TEST RESULTS FOR INDIVIDUAL SPECIES

| Species | Specific gravity (od. vol.) | Moisture content (percent) | Ultimate tensile strength (psi) | Maximum strain [1] (microin. per in.) | Modulus of elasticity (1,000,000 psi) First cycle | Modulus of elasticity (1,000,000 psi) Last cycle | Assumed stress level [2] (percent) | Initial strain [3] (microin. per in.) | Creep (microin. per in.) At cycle numbers 10 | 20 | 50 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Determa (*Ocotea rubra*) | 0.55 | 9.8 | 13346 | 8184 | 1.6912 | 1.6945 | 30 | 2187 | 13 | 16 | 27 | 36 |
| | | | | | | | 40 | 3267 | 49 | 64 | 96 | 137 |
| | | | | | | | 50 | 4008 | 62 | 88 | 131 | 179 |
| | | | | | | | 60 | 4132 | 78 | 115 | 185 | 255 |
| Control | .55 | 9.5 | 12710 | 8652 | | | 70 | 5077 | 100 | 144 | 276 | 422 |
| | | | | | | | 80 | 5498 | 128 | 204 | 357 | 532 |
| Ceiba (*Ceiba pentandra*) | .25 | 12.5 | 4196 | 8938 | 0.5085 | 0.5128 | 30 | 3216 | 61 | 82 | 116 | 134 |
| | | | | | | | 40 | 3941 | 85 | 120 | 188 | 264 |
| | | | | | | | 50 | 4174 | 78 | 111 | 205 | 298 |
| | | | | | | | 60 | 5601 | 165 | 250 | 425 | 658 |
| Control | .25 | 13.0 | 4462 | 9139 | | | 70 | 5786 | 176 | 254 | 454 | 736 |
| | | | | | | | 80 | 5586 | 132 | 210 | 354 | 552 |
| Kaneelhart (*Licaria cayennensis*) | 1.05 | 11.1 | 28351 | 8302 | 1.0890 | 1.0324 | 30 | 2480 | 11 | 17 | 25 | 38 |
| | | | | | | | 40 | 3355 | 29 | 44 | 59 | 91 |
| | | | | | | | 50 | 3699 | 45 | 67 | 101 | 140 |
| | | | | | | | 60 | 4470 | 73 | 108 | 151 | 232 |
| Control | 1.06 | 11.4 | 31060 | 7992 | | | 70 | 5399 | 100 | 158 | 285 | 455 |
| | | | | | | | 80 | 6276 | 247 | 386 | 871 | 1536 |
| Timbauba (*Enterolobium Schomburgkii*) | .95 | 11.6 | 34597 | 11404 | 3.5067 | 3.4810 | 30 | 3021 | 13 | 22 | 35 | 56 |
| | | | | | | | 40 | 4057 | 45 | 71 | 112 | 148 |
| | | | | | | | 50 | 4974 | 81 | 128 | 222 | 337 |
| | | | | | | | 60 | 6022 | 134 | 227 | 447 | 742 |
| Control | .96 | 11.1 | 34295 | 11128 | | | 70 | 6679 | 193 | 327 | 641 | 1069 |
| | | | | | | | 80 | 7458 | 299 | 517 | 1025 | 1725 |
| Cedro (*Cedrela Tonduzii*) | .40 | 13.1 | 14259 | 10137 | 1.5489 | 1.5466 | 30 | 2923 | 19 | 30 | 46 | 61 |
| | | | | | | | 40 | 3709 | 32 | 46 | 77 | 99 |
| | | | | | | | 50 | 4479 | 55 | 90 | 150 | 215 |
| | | | | | | | 60 | 5698 | 114 | 184 | 363 | 610 |
| Control | .40 | 12.4 | 14183 | 10201 | | | 70 | 6979 | 219 | 375 | 769 | 1324 |
| | | | | | | | 80 | 7020 | 229 | 372 | 744 | 1274 |
| Redwood (*Sequoia sempervirens*) | .37 | 10.5 | 9602 | 8257 | 1.2739 | 1.2700 | 30 | 2022 | 10 | 13 | 25 | 33 |
| | | | | | | | 40 | 3864 | 71 | 97 | 166 | 209 |
| | | | | | | | 50 | 3583 | 47 | 64 | 100 | 153 |
| | | | | | | | 60 | 5185 | 90 | 138 | 262 | 410 |
| Control | .36 | 8.9 | 8905 | 7708 | | | 70 | 4708 | 65 | 104 | 179 | 284 |
| | | | | | | | 80 | 4731 | 64 | 83 | 150 | 214 |
| Hickory (*Carya* sp.) | .82 | 12.5 | 31863 | 14566 | 2.7514 | 2.7379 | 30 | 3412 | 39 | 49 | 68 | 98 |
| | | | | | | | 40 | 4279 | 55 | 82 | 133 | 187 |
| | | | | | | | 50 | 5468 | 114 | 182 | 290 | 445 |
| | | | | | | | 60 | 7684 | 334 | 558 | 1012 | 1668 |
| Control | .80 | 11.4 | 29626 | 13239 | | | 70 | 8046 | 387 | 622 | 1175 | 1918 |
| | | | | | | | 80 | 8392 | 396 | 670 | 1284 | 2114 |
| Chewstick (*Symphonia globulifera*) | .69 | 11.9 | 29989 | 10597 | 3.2067 | 3.1776 | 30 | 2847 | 14 | 22 | 38 | 53 |
| | | | | | | | 40 | 3757 | 39 | 55 | 86 | 130 |
| | | | | | | | 50 | 5230 | 95 | 142 | 271 | 445 |
| | | | | | | | 60 | 5180 | 91 | 145 | 275 | 441 |
| Control | .70 | 10.2 | 29693 | 10422 | | | 70 | 6405 | 187 | 294 | 615 | 1050 |
| | | | | | | | 80 | 7201 | 231 | 404 | 826 | 1716 |
| White Pine (*Pinus strobus*) | .37 | 11.2 | 14564 | 11113 | 1.4279 | 1.0173 | 30 | 2188 | 22 | 30 | 47 | 59 |
| | | | | | | | 40 | 3715 | 77 | 114 | 186 | 258 |
| | | | | | | | 50 | 3664 | 47 | 63 | 95 | 118 |
| | | | | | | | 60 | 6195 | 320 | 499 | 868 | 1363 |
| Control | .35 | 10.6 | 11716 | 9569 | | | 70 | 4969 | 102 | 156 | 247 | 360 |
| | | | | | | | 80 | 5785 | 162 | 239 | 417 | 645 |

[1] Strain at failure after 100 stress cycles; creep strain included.
[2] Percentage of average ultimate tensile stress of control specimens.
[3] Strain at the assumed stress level on the first cycle.

The calculated slopes, $b_1$ and $b_2$, which describe the plane for each species, are listed in Table 2. An example of the creep-initial strain relationship for white pine at the 10th, 20th, 50th, and 100th cycles is shown in Fig. 3. The plotted regression lines were obtained from the fitted plane for this species.

From the analysis shown in Table 3, it can be seen that there is a highly significant difference between the regressions of the various species. An examination of Table 4, in which the average residual for each species has been expressed as the percent difference from the general plane, reveals a range of values from + 18.5 percent for ceiba to — 9.7 percent for redwood. These species differences, however, account for only 27.77 percent of the variation about the average regression for all species. Furthermore, the root mean square residual of 18.77 percent that is achieved by pooling the residuals from the individual planes for each species is not appreciably less than the root mean square residual of 22.11 percent obtained by using a single generalized plane for all species. The general creep-cycle number and creep-initial strain relationships for all species tested are shown in Fig. 4.

A plot of the creep-initial strain relationships at 100 cycles for all 9 species, as shown in Fig. 5, illustrates the limited degree of variation of individual species from the general curve. Although differences between species were relatively small, an effort was made to account for them by plotting the average residual from the general curve for each species against factors such as specific gravity, slope of grain, ultimate strain, modulus of elasticity, and the ratio modulus of elasticity/specific gravity, which presumably is a measure of fibrillar orientation or crystallinity. The best correlation was found with the ratio modulus of elasticity/specific gravity, but this accounted for only 34.6 percent of the variation between individual species.

[3] Numbers in parentheses refer to the Literature Cited at the end of this paper.

With only nine residuals to plot against the various factors that might account for small portions of the remaining variance, it was not thought advisable to attempt a multivariate analysis because of the extreme probability of attributing significance to factors that in reality had no significant effect on the variance.

Table 2.—GENERAL AND INDIVIDUAL SPECIES CONSTANTS FOR CREEP-INITIAL STRAIN-CYCLE NUMBER PLANES[1]

| Common name | $b_1$ | $b_2$ |
|---|---|---|
| Determa | 0.12206 | —0.17432 |
| Ceiba | .10797 | — .08675 |
| Kaneelhart | .14193 | — .26406 |
| Timbauba | .13659 | — .29222 |
| Cedro granadino | .12819 | — .24729 |
| Redwood | .10738 | — .16297 |
| Hickory | .11343 | — .17652 |
| Chewstick | .13138 | — .25691 |
| White pine | .11272 | — .14919 |
| General | .11923 | — .18547 |

[1] General equation for the creep-initial strain cycle number plane is

$$\log\left(\frac{\Delta e_1 + c}{c}\right) = b_1 e_1 \log N + b_2 \log N$$

where $\Delta e_1$ = creep, microinches per inch; $e_1$ = initial strain, 1,000 microinches per inch; N = cycle number; c = 60; and $b_1$ and $b_2$ are the constants listed above.

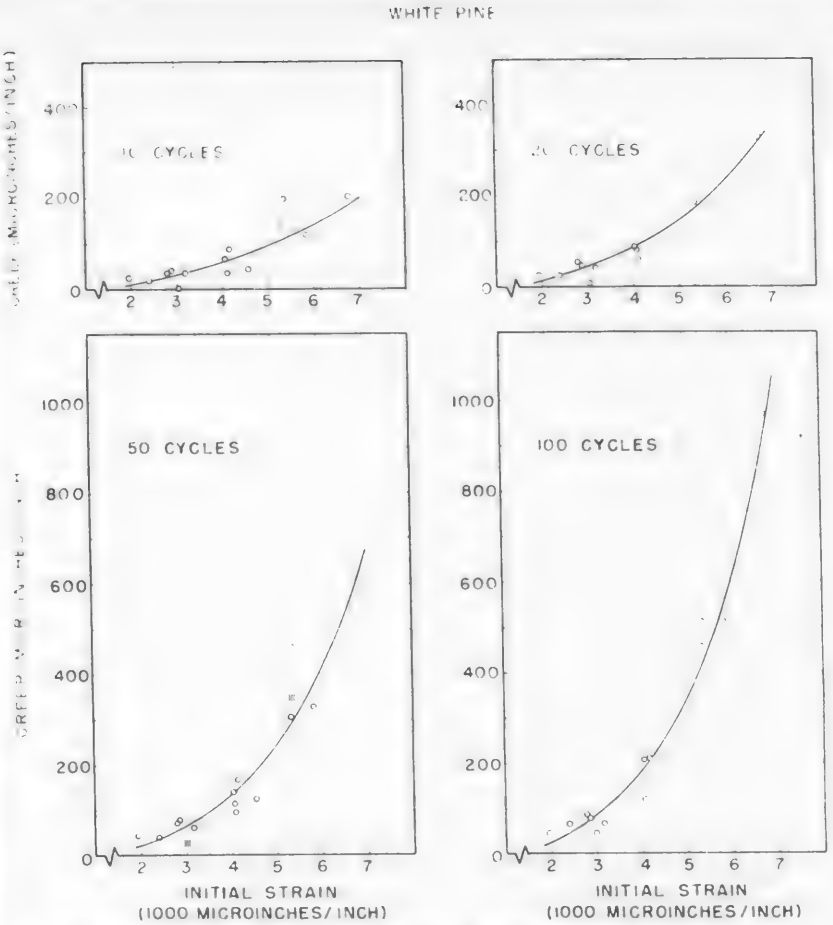


**Fig. 3.—Creep-initial strain relationships for white pine at the 10th, 20th, 50th and 100th cycles.**

The importance of initial strain as a basic controlling factor of creep in wood under repeated loading conditions is emphasized when comparison is made with creep-cycle number curves obtained when other factors are considered as the basis for this relationship.

Fig. 6 shows the creep-cycle number curves for all 9 species at a constant percentage of their ultimate tensile strengths, while Fig. 7 illustrates the relationship at a fixed percentage of ultimate tensile strain for each species. The data were not analyzed in this manner so that both of these relationships have been constructed by determining the initial strain at the desired condition of stress or percent ultimate strain. Creep values were then obtained by use of the creep-initial strain-cycle number equation for each species.

For comparative purposes, the creep-cycle number relationships at a fixed initial strain level are presented in Fig. 8. It is obvious from these illustrations that species which showed widely differing creep behavior on the basis of a fixed percent of ultimate tensile stress or strain show a remarkable similarity, which has been previously discussed, on the basis of a fixed initial strain. It might also be mentioned that the difference between species on the basis of stress alone was extremely great. The same stress which, in the species with the lowest tensile strength, could be resisted without failure but with a high creep response, resulted in an initial strain so low that creep was negligible in the species with the highest tensile strength.

The effect of repetitive stressing on the modulus of elasticity was investigated by plotting the ratio of the modulus of elasticity in the 100th cycle to that in the first cycle against the initial strain for each specimen. Linear regressions were fitted to each of these modulus of elasticity ratio-initial strain plots by the method of least squares. The analysis of these regression lines, shown in Table 5, indicates that the average, or combined, slope for all species is not significantly different from zero. There are significant differences between species, however when tested individually, only one of the species, ceiba, showed a significant effect of cycling on the modulus of elasticity ratio. Of the other eight species, the nonsignificant slopes were both positive and negative.

The effect of repetitive stressing on ultimate tensile strength was similarly investigated by plotting the ratio of ultimate tensile strength for each specimen to that of its control against the initial strain to which the individual specimens were subjected. The analysis, shown in Table 6, indicates that the average, or combined, slope for all species is not significant, although again there are significant differences between species. When tested individually, the only regression of this type which proved to be significant was that for white pine. Of the other eight species, some of the nonsignificant slopes were positive and some negative.

The effect of repeated loading on ultimate tensile strain was also investigated for each species by plotting the difference between the ultimate tensile strain of the individual specimens and that of their respective controls against initial strain. In this case, two species, ceiba and chewstick, exhibited positive significant slopes. The slopes for the other seven species, although not statistically significant individually, proved to be consistently positive. The analysis of variance, Table 7, indicates that there are no significant dif-

Table 3.—ANALYSIS OF DIFFERENCES IN SPECIES REGRESSIONS OF CREEP ON INITIAL STRAIN AND CYCLE NUMBER

| Term | Degrees of freedom | Sum of squares | Mean squares | F | Significance[1] |
|---|---|---|---|---|---|
| Difference between species | 16 | 1.291586 | 0.080724 | 14.47 | *** |
| ror | 602 | 3.358699 | 0.005579 | | |
| tal | 618 | 4.650285 | 0.007525 | | |

[1] $0.1 r^2 = 27.77$
oot mean square residual from the general plane = 22.11 percent
ot mean square residual from the pooled residuals of individual planes = 18.77 ercent

Level of significance indicated by the following symbol:
***Significant at the 0.1 percent level of probability.

Table 4.—AVERAGE RESIDUALS FOR INDIVIDUAL SPECIES FROM THE GENERAL PLANE FOR THE CREEP-INITIAL STRAIN-CYCLE NUMBER RELATIONSHIP

| Species | Average residual[1] | Percent difference from general plane |
|---|---|---|
| Determa | 0.031988 | 7.6 |
| Ceiba | 0.073662 | 18.5 |
| Kaneelhart | 0.022038 | 5.2 |
| Timbauba | 0.019374 | —4.6 |
| Cedro granadino | 0.027325 | 6.5 |
| Redwood | 0.040331 | —9.7 |
| Hickory | 0.034256 | —8.2 |
| Chewstick | 0.019230 | —4.5 |
| White pine | 0.013108 | 3.1 |

[1] Average residuals expressed in terms of $\log\left(\frac{\Delta e_1 + c}{c}\right)$ where $\Delta e_1$ = creep, microinches per inch; c = 60.

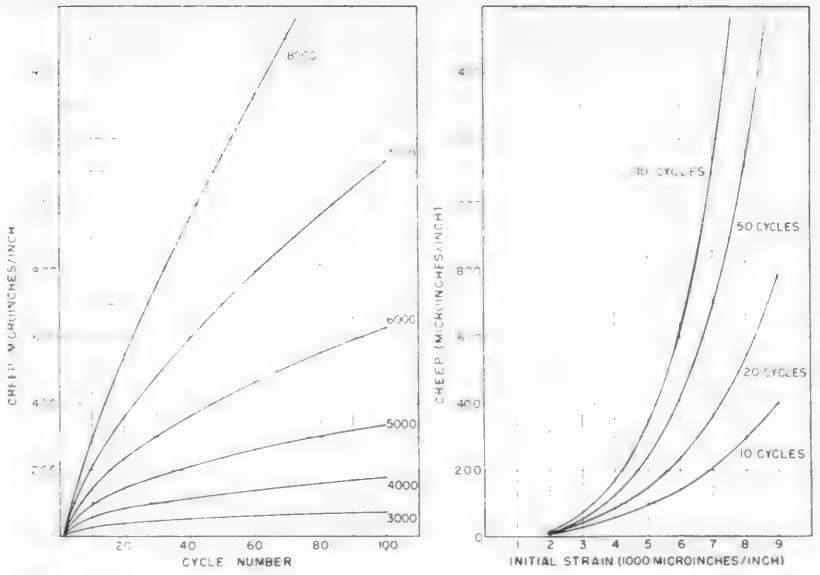


Fig. 4.—General creep-cycle number and creep-initial strain relationships for all species tested.

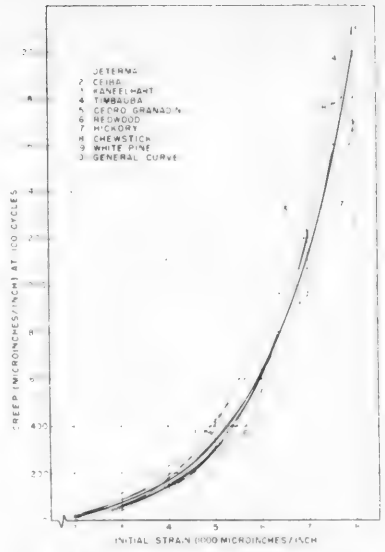


Fig. 5.—Creep-initial strain relationships for each species at 100 cycles illustrating the variability about the general curve.

ferences between slopes or between means for individual species. This justified the fitting of a combined regression to the data for all species, which proved to be very highly significant. An example of the effect of repeated loading on the modulus of elasticity, ultimate tensile stress, and ultimate tensile strain is shown for chewstick in Fig. 9.

The consistent positive slope of the ultimate strain difference-initial strain plot for all species seemed to warrant further investigation. An attempt was made to correlate the difference between the ultimate tensile strain, which includes creep strain, of a specimen and that of its control with the creep that occurred during the cycling period. Linear regressions were fitted to this relationship for each of the nine species by the method of least squares. It was found that all species exhibited positive slopes and that 6 of these 9 slopes were significant. The analysis of variance for all species, shown in Table 8, indicated no significant difference between either the slopes or the means for all nine species. This nonsignificance justified the fitting of a single line representing the combined slope of all the species, which proved to be very highly significant. If the increase in ultimate tensile strain due to cycling were accounted for entirely by the creep that occurred during the cycling period, the slope of this regression would be equal to one and pass through the zero-zero coordinate. Fig. 10 illustrates the similarity between the combined slope of the data and the theoretical condition suggested. A statistical comparison of these two lines indicated that they did not differ significantly.

## Discussion of Results

The design of this experiment called for the measurement of creep under repetitive loading conditions in tension parallel to the grain at various percentages of the ultimate tensile strength of the individual species. The widely divergent creep response, as illustrated in Fig. 6, for the nine species tested shows no indication of a common behavior for wood on this basis.

It was found, however, that the creep behavior for various species was quite similar with respect to the initial strain to which they were subjected. For this reason, the creep-initial strain relationship for all species was examined, and it was found that, over the range of initial strains tested, this relationship could be satisfactorily described by an exponential function.

There are indications from investigations of creep behavior under sustained loading conditions (10, 20) that, at low strain levels, the creep-initial strain relationship may be linear. In this work, the range of data is primarily above the region in which linearity may exist. The exponential nature of the creep-percent ultimate tensile strength relationship in this range has been reported for sustained loading conditions in tension parallel to the grain (9, 10).

It was also found that the creep-cycle number relationship over the range of data for all species could be satisfactorily described by a power function. Under sustained tensile load conditions, the creep-time relationship

Table 5.—ANALYSIS OF THE REGRESSIONS OF THE MODULUS OF ELASTICITY RATIO AS A FUNCTION OF INITIAL STRAIN

| Term | Degrees of freedom | Sum of squares | Mean square | F | Significance[1] |
|---|---|---|---|---|---|
| Pooled slopes | (9) | 0.005302 | 0.000589 | 3.05 | ** |
| Combined slope | 1 | 0.000280 | 0.000280 | 1.45 | NS |
| Difference between slopes | 8 | 0.005022 | 0.000628 | 3.25 | ** |
| Difference between means | 8 | 0.005617 | 0.000701 | 3.63 | *** |
| Error | 135 | 0.026082 | 0.000193 | | |
| Total | 152 | 0.037001 | | | |
| Correction for mean | 1 | 152.177149 | | | |

$100\ r^2 = 16.89$

[1]Level of significance indicated by the following symbols:
* Significant at the 5.0 percent level of probability.
** Significant at the 1.0 percent level of probability.
*** Significant at the 0.1 percent level of probability.
NS Nonsignificant.

Table 6.—ANALYSIS OF THE REGRESSIONS OF THE ULTIMATE TENSILE STRESS RATIO AS A FUNCTION OF INITIAL STRAIN

| Term | Degrees of freedom | Sum of squares | Mean square | F | Significance |
|---|---|---|---|---|---|
| Pooled slopes | (9) | 0.708373 | 0.078708 | 2.60 | * |
| Combined slope | 1 | 0.079439 | 0.079439 | 2.63 | NS |
| Difference between slopes | 8 | 0.628934 | 0.078617 | 2.60 | * |
| Difference between means | 8 | 1.293299 | 0.161662 | 5.34 | *** |
| Error | 137 | 4.147349 | 0.030273 | | |
| Total | 154 | 6.149021 | | | |
| Correction for mean | 1 | 170.774119 | | | |

$100\ r^2 = 14.59$

[1]Level of significance indicated by the following symbols:
* Significant at the 5.0 percent level of probability.
** Significant at the 1.0 percent level of probability.
*** Significant at the 0.1 percent level of probability.
NS Nonsignificant.

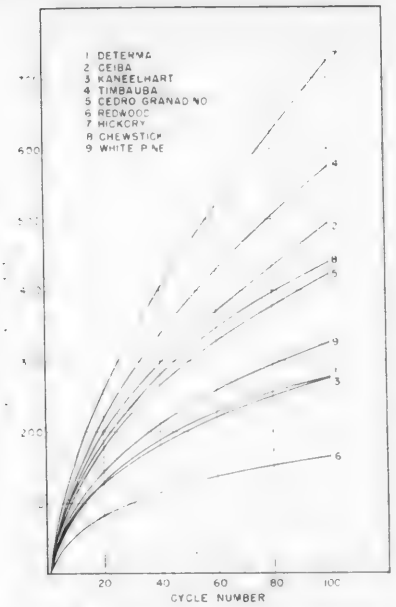


**Fig. 6.—Creep-cycle number relationships at 60 percent of the ultimate tensile strength for each species.**

has been shown to be of a similar nature (14).

No previous work has attempted to describe creep in wood as a joint function of initial strain and cycle number. Such a relationship was developed in this study so that differences between species could be tested over the entire range of data at one time. Although significant statistical differences were found between species, these differences are relatively small, and an estimate of creep for any of the species based on the general relationship would exhibit only a slightly greater error than one made from the relationship for the particular species. This difference is especially small when one considers the large differences in specific gravity and anatomical structure exhibited by these nine species.

Work carried out at the Australian Forest Products Laboratory and reported in the C.S.I.R.O. Annual Reports (2) indicates that, in bending, the creep response under a sustained load is not significantly different for two such structurally different species as hoop pine (*Araucaria cunninghamii*) and mountain ash (*Eucalyptus regnans*). They have further reported that, under a sustained load, beams of blackbutt (*Eucalyptus pilularis*) and mountain ash showed similar creep behavior under both dry and green conditions. Unfortunately, the basis on which they have behaved similarly is not mentioned.

If initial strain is a basic factor in determining the amount of creep for all species, there is an implication that creep is a response controlled by the fundamental nature of wood—that is, by its molecular structure. It is known that the glucose anhydride unit is the same from any source of cellulose (16), and that, furthermore, the cell wall density of different species is a relatively constant value (5, 18). The fact that sorption behaviour, which is dependent primarily on cellulose structure and configuration, is quite similar for diverse species of wood (17) also supports the idea of a similar molecular organization. It seems feasible that this basic structure might respond in a similar manner, irrespective of species, when subjected to a given amount of strain.

Should this be the case, and considering the number of factors that might affect the response of this basically similar structure, it is not surprising that various species, although very similar in behavior, still show statistically significant differences. At the molecular level, such factors as variation in crystallinity, orientation of the crystalline regions, and differences in the degree of lateral bonding in disordered regions might all be expected to influence the creep response. At the gross structural level, it would seem likely that slope of grain, fibril angle, and such anatomical factors as percent ray volume might also be of importance. With the possibility that all of these variable factors may affect the creep response of an individual species or specimen, the variation that still exists between species, when the single factor of initial strain is accounted for, does not seem very large.

In attempting to account for species differences, little correlation was found between the species residuals and any of the factors tested. The correlation of the residual with specific gravity was negligible. The adjustment of modulus of elasticity for specific gravity, presumably a measure of fibril angle, had the highest correlation, but it still accounted for only 34.6 percent of the variance. It would seem reasonable that deviations from the axial load direction caused by a lower order of crystalline orientation, or, in fact, the degree of crystallinity itself could also influence this value. The measurement of other factors that might affect the creep response, such as degree of lateral bonding, crystallinity, and orientation, though undoubtedly of importance (1, 19), were beyond the scope of this study.

The writer proposes the following explanation for the similarity in rheological behavior of different species with respect to initial strain. When a cellulose network is subjected to an instantaneously applied load, the immediate strain response is elastic and primarily dependent on valence-angle changes within the cellulose chain as well as in increase in both primary-bond lengths within the cellulose chain and hydrogen-bond lengths between cellulose chains. The elasticity of these various components is different, that of a primary bond being highest. The deformations of these components are additive, so that the overall elastic modulus of the network depends on the distribution of the cellulose chains within the network. Theoretical calculations of Young's modulus based on molecular forces in the crystalline, or highly ordered, regions result in an upper limit value that is approached by the dynamic modulus of highly ordered natural fibers such as ramie, which are dried under tension to further increase their crystallinity (13).

If the factor of time enters this picture, the total deformation of the system increases due to movement and adjustment of cellulose chains within the regions of low order. The degree to which this adjustment takes place is again dependent on the distribution and configuration of the cellulose chains.

When a load is applied to this system at a constant rate, the strain response at any instant is partly due to the elastic deformation and partly due to the time-dependent or creep deformation, but in any case its total magnitude is a result of the distribution of cellulose chains within the network.

Considering a test in which the load is applied in a repetitive manner, the successive periods of creep and recovery result in a creep deformation at the given load level that is made up of

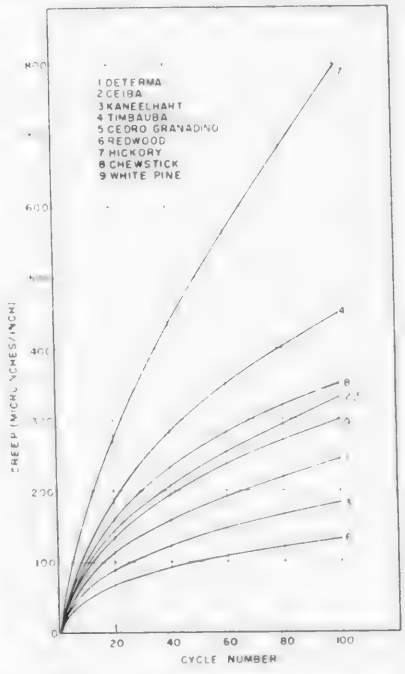


**Fig. 7.—Creep-cycle number relationships at 50 percent of the ultimate tensile strain for each species.**

Table 7.—ANALYSIS OF THE REGRESSIONS OF CHANGE IN ULTIMATE TENSILE STRAIN AS A FUNCTION OF INITIAL STRAIN

| Term | Degrees of freedom | Sum of squares | Mean square | F | Significance[1] |
|---|---|---|---|---|---|
| Pooled slopes | (9) | 80.537733 | 8.948637 | 3.52 | *** |
| Combined slope | 1 | 70.256410 | 70.256410 | 27.64 | *** |
| Difference between slopes | 8 | 10.281323 | 1.285165 | 0.51 | NS |
| Difference between means | 8 | 32.675839 | 4.084480 | 1.61 | NS |
| Error | 134 | 340.631672 | 2.542027 | | |
| Total | 151 | 453.845244 | | | |
| Correction for mean | 1 | 16.345553 | | | |

$100\ r^2 = 19.12$

[1] Level of significance indicated by the following symbols:
*** Significant at the 0.1 percent level of probability.
NS Nonsignificant.

Table 8.—ANALYSIS OF THE REGRESSIONS OF THE CHANGE IN ULTIMATE TENSILE STRAIN AS A FUNCTION OF CREEP AT 100 CYCLES

| Term | Degrees of freedom | Sum of squares | Mean square | F | Significance[1] |
|---|---|---|---|---|---|
| Pooled slopes | (9) | 117.720770 | 13.080086 | 5.68 | *** |
| Combined slope | 1 | 112.053017 | 112.053017 | 48.68 | *** |
| Difference between slopes | 8 | 5.667759 | 0.708470 | 0.31 | NS |
| Difference between means | 8 | 27.698414 | 3.462302 | 1.50 | NS |
| Error | 134 | 308.426054 | 2.301687 | | |
| Total | 151 | 453.845244 | | | |
| Correction for mean | 1 | 16.345553 | | | |

$100\ r^2 = 38.17$

[1] Level of significance indicated by the following symbols:
*** Significant at the 0.1 percent level of probability.
NS Nonsignificant.

both recoverable and nonrecoverable components. A large portion of the primary creep is recovered during the unloading period of each cycle. The increment of strain increase decreases with each successive cycle so that the general strain tendency is toward a new equilibrium position dependent on the distribution of cellulose chains, the applied load, and the test conditions.

As previously mentioned, relatively constant cell-wall density and similar sorption behavior for diverse species of wood are indicative of a fairly constant low-order—high-order relationship, both qualitatively and quantitatively. To the extent that this is true, the cellulose network in wood, regardless of its source, should react to a given load with a similar strain response, both immediate and delayed.

In transferring from the stress-strain relationships of the cellulose network at a molecular level to those same relationships at a gross level, it must be kept in mind that the strain per unit length remains the same, whereas the load per unit area on a gross scale is very different, primarily because of differences in specific gravity. Since strains measured at the gross level remain comparable at the molecular level, this single factor is the best indication of an equivalent stress condition at the molecular level. The creep response of the uniform cellulose network to a given stress at the molecular level is relatively constant, and this increase in molecular strain is reflected by a similar change in gross strain.

With regard to the importance of initial strain to the rheological behavior of wood, it is of interest to note the results of work by Press (15) on the creep and creep recovery of viscose rayon yarn. Press proposed that the behavior of this material was related to the degree of extension. It was found that at extensions below 0.75 percent, creep recovery was complete. At extensions between 0.75 and 4.0 percent, creep recovery was not complete unless the material was subjected to wetting and redrying. Beyond an extension of 4.0 percent, the recovery was not complete even after the conditioning treatment.

This explanation has not taken into consideration the effect that lignin may have on rheological behavior. Information is not available on this subject, but it might be assumed from the larger creep rates and ultimate tensile strains exhibited by the unlignified cellulosic high polymers that the lignin effect is primarily one of restriction. Considerations of the differential fibril angle in the various layers of the fiber wall also have been neglected. The approximately axial fibril orientation in the $S_2$ layer of the fiber wall causes it to carry the major part of the load, and, therefore, its influence on creep must be of primary importance. Shear stresses that develop in the middle lamella in transferring tensile stresses from fiber to fiber may have an influence on wood's creep behavior, but sufficient information is not available to evaluate this effect. A study of the rheological behavior of single wood fibers might lead to a clarification of some of these points.

It appears from the results of this study that 100 stress cycles, within the range of initial strains tested, do not appreciably affect the modulus of elasticity of these species. Even though the pooled slopes were found to be statistically significant, the slopes of all the species except ceiba were not individually significant. Some of the nonsignificant slopes were negative while others were positive. It seems highly unlikely that, if the effect were appreciable, it would be inconsistent for different species.

The same reasoning may be applied to the effect of repeated loading on ultimate tensile strength. Although it has been shown (11) that repeated loading in tension parallel to the grain reduces ultimate tensile strength, it appears that 100 stress cycles within the range tested are not sufficient to reveal this decrease. Again, the pooled slopes were statistically significant, but individual slopes were both positive and negative, and only white pine showed a significant decrease in ultimate strength.

Certain rather important inferences may be drawn from the results concerning the effect of repeated loading on ultimate strain. The regressions of the difference between ultimate tensile strain of the individual specimens and that of their respective controls against creep during the cycling period were not significantly different among species, and the combined slope proved to be very highly significant. The coefficient of determination of only 38 percent for this regression is probably due to the extreme natural variability in ultimate tensile strain, which tends to mask the influence of creep on the change that occurs. The single line representing the combined slope for all species has been plotted in Fig. 10 and compared with the theoretical line that would exist if creep accounted for the increase in tensile strain entirely. These two lines did not differ significantly, but again this may be due primarily to the variability in ultimate tensile strain. When the combined slope is considered, it might appear that the ultimate tensile strain of a specimen is reduced when subjected to 100 cycles at an initial strain which results in a creep response of less than 285 microinches per inch. This seems highly improbable, and may well be the result of fitting a linear regression to a relationship that in reality has two distinct stages. For this reason, the portion of the regression line below the zero axis has been dotted.

It may be that the increase in ultimate strain is due only to the irrecoverable portion of creep, so that cycling at initial strains below the threshold of set does not appreciably affect the ultimate tensile strain. King (10) has indicated the existence of such a threshold under sustained tensile loads and in all probability one exists under repeated loading conditions as well

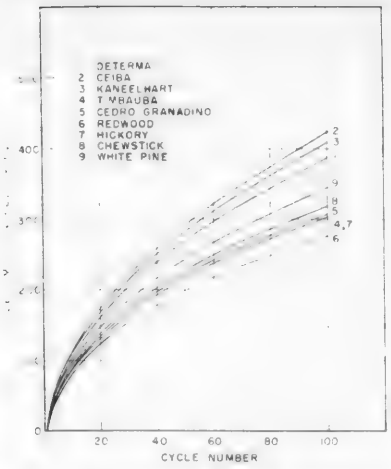


**Fig. 8.—Creep-cycle number relationships at 5000 microinches per inch initial strain for each species.**

If this hypothesis is correct, the data used in determining the combined slope shown in Fig. 10 should more properly be fitted with a horizontal line at zero change in ultimate tensile strain up to the creep value that corresponds to the threshold of set. Unfortunately, the data for individual species do not justify the application of this rigorous treatment. The conclusion must be drawn that, although the increase in ultimate tensile strain with cycling is related to the creep that has occurred during the cycling period, the present results do not justify attributing it to any particular portion of this creep.

It should be noted that an increasing ultimate tensile strain due to any time effects is contrary to the opinion, expressed by several workers (4, 6, 7, 12, 20), that ultimate strain is relatively constant. These observations point to the study of the failure process in wood as an interesting field of investigation.

## Conclusions

The creep response of wood under repeated loading in tension parallel to the grain is primarily controlled by the initial strain to which the material is subjected. Although individual species still exhibited statistically significant differences on an initial strain basis, these differences are small, especially when the numerous other factors that might influence this response are considered. Several of these other factors were investigated, but failed to account for an appreciable amount of the residual variance.

The creep-initial strain relationship for all species was found to be satisfactorily described by an exponential function within the range of data studied. Creep-cycle number relationships are adequately described for at least 100 cycles by a power function.

Repetitive stressing for 100 cycles in tension parallel to the grain within the range of these test conditions does not appear to have an appreciable effect on the modulus of elasticity of wood.

Although it is known that repeated loading in tension parallel to the grain does in time reduce the ultimate strength of wood, it was found that, in general, 100 cycles of stress of the short duration employed are not sufficient to incur any appreciable decrease in strength.

Emphasis has been placed on the importance of initial strain in determining creep behavior. In considering the effect of repetitive loading on modulus of elasticity and ultimate stress, however, it must be kept in mind that the relationships cannot be expressed in general terms as far as initial strain is concerned, since the range of initial strains for individual species differs. More properly, the general relationship on an initial strain basis is applicable for a particular species, providing it is within the range of 30 to 80 percent of the ultimate tensile strength of that species.

It appears that ultimate tensile strain of wood, including accumulated creep, increases after repetitive stressing in tension parallel to the grain. There is an indication that this increase in ultimate strain is a result of the increased strain due to the creep that has occurred during the cycling period.

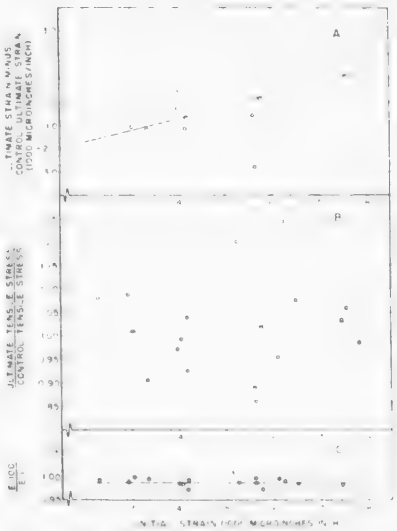


**Fig. 9.—Effect of 100 cycles of repeated stressing on properties of chewstick. A. Difference between ultimate strain of repeatedly stressed specimens and that of previously unstrained controls plotted against initial strain. B. Ratio of ultimate tensile stress of repeatedly stressed specimens to that of previously unstressed controls plotted against initial strain. C. Ratio of modulus of elasticity on the 100th cycle of repeated stress to that on the 1st cycle plotted against initial strain.**

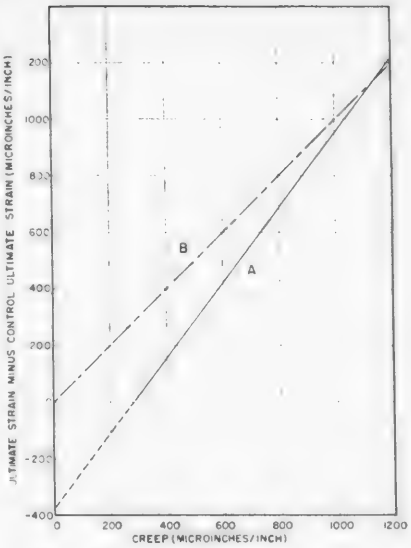


**Fig. 10.—Comparison of the combined regression of change in ultimate strain against creep at 100 cycles (A) with the theoretical line of equivalence between these two factors (B).**

It is suggested that the nonrecoverable portion of creep may be equivalent to the increase in ultimate tensile strain.

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# Detection of Brown Rot

## WITH OSMIUM TETROXIDE STAIN[1]

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**Staining with osmium tetroxide provides a rapid method of detecting brown-rot fungi in either incipient or advanced stages. The technique can be used for early detection of brown rot in pulpwood and other products in storage and in field surveys where type of decay must be determined.**

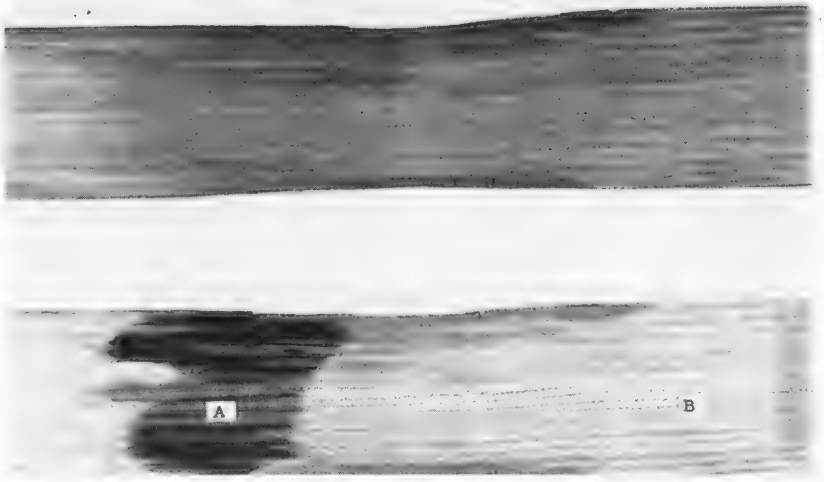


Fig. 1.—Top, untreated sample. Bottom, same sample treated with a 1 percent solution of osimum tetroxide streaked across the grain over brown-rot (A) and over sound wood (B).

WOOD PATHOLOGISTS OFTEN FIND it necessary to determine whether particular wood samples have been infected with wood-rotting fungi and, if so, the type of decay involved. This work could be greatly facilitated by simple staining reactions that are specific for decayed wood or could be used to distinguish between the two major types of wood decay—white rot and brown rot. Existing methods for detecting decay in wood are often insufficiently reliable when the decay has progressed only to incipient stages, or are so time consuming that they are difficult to apply routinely.

### Existing Methods are Limited

A recent survey of methods for the detection and quantitative evaluation of decay in wood has been prepared by Hartley.[3] Visual features that have been used for diagnosis of decayed wood include: Abnormal color, brashness, reduced strength, abnormal longitudinal shrinkage, checking perpendicular to the grain, the presence of hyphae of decay fungi, and bore holes in the wood cell walls. Only the presence of hyphae and bore holes are definitive indicators of decayed wood, particularly when the decay has progressed only to incipient stages. For example, the color of decayed wood as well as normal wood is highly variable and may be obscured by weathering, surface molds, or staining fungi. Brashness, reduced strength, abnormal shrinkage, and checking perpendicular to the grain are characteristic also of compression and tension wood. Abnormal shrinkage and checking patterns may not be evident in incipient stages of brown rot and have rarely, if ever, been observed in wood decayed by white-rot fungi. The presence of hyphae is positive evidence of infection by a decay fungus only if the hyphae have clamp connections.

The presence of decay fungi can be ascertained with reasonable certainty by microscopical examination of the wood for bore holes, or by the cultural isolation of fungi that are known to cause wood decay. Both of these methods, however, are quite laborious; they require that the investigator have some experience in sectioning wood or in cultural isolation procedures, as well as the ability to

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[1] A contributed paper received May 4, 1960.
[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3] Hartley, C. Evaluation of Wood Decay Experimental Wood. U. S. Forest Products Laboratory Report No. 2116, 1958.

**Table 1.—TIME REQUIRED FOR STAINING OF SOUND AND DECAYED WOOD AFTER TREATMENT WITH OSMIUM TETROXIDE**

| Type of Rot | Decay organism | Wood species |
|---|---|---|
| | Less than 5 minutes | |
| | *Coniophora puteana* | Southern pine |
| | *Daedalia quercina* | do |
| | *Fomes subroseus* | do |
| | *Lentinus lepideus* | do |
| | *Lenzites saepiaria* | do |
| | *Lenzites trabea* | do |
| | *Polyporus schweinitzii* | do |
| | *Poria oleracea* | do |
| Brown-Rot | *Poria cocos* | do |
| | *Poria incrassata* | do |
| | *Poria monticola* | Sitka spruce |
| | *Poria monticola* | Sweetgum |
| (Incipient) | *Poria monticola* | do |
| (Intermediate) | *Poria monticola* | do |
| (Advanced) | *Poria monticola* | do |
| | *Poria radiculosa* | Southern pine |
| | *Poria vaillantii* | do |
| | *Poria xantha* | do |
| | More than 20 minutes | |
| | *Corticium invesiens* | Southern pine |
| | *Fomes applanatus* | Sweetgum |
| | *Fomes rimosus* | Southern pine |
| | *Fomes rimosus* | Sweetgum |
| | *Odontia bicolor* | Southern pine |
| | *Odontia spathulata* | do |
| | *Odontia spathulata* | Sweetgum |
| White-Rot | *Polyporus gilvus* | Southern pine |
| | *Polyporus gilvus* | Sweetgum |
| | *Polyporus tulipiferae* | do |
| | *Poria nigrescens* | do |
| | *Poria nigrescens* | Southern pine |
| | *Schizophyllum commune* | Sweetgum |
| | *Schizophyllum commune* | Southern pine |
| None (Sound Wood) | ---------- | Southern pine |
| | ---------- | Sitka spruce |
| | ---------- | Sweetgum |

distinguish wood-rotting fungi from nonwood-rotting fungal species. Also, bore holes often are not conspicuous.

For these reasons, relatively simple staining reactions that are specific for decayed wood can provide a useful adjunct to existing methods of decay evaluation.

## Stain Reactions on Decayed Wood

Since many wood-rotting fungi produce organic acids that increase the acidity of the wood, pH indicators have often been suggested as staining reagents for the detection of decay in wood. Lindgren[4] has found the pH indicator, Alizarine Red S, to be helpful in the identification of unseasoned southern pine products decayed by the white-rot fungus, *Peniophora gigantea*. The reagent can be used to detect incipient as well as advanced stages of decay by this organism. It has considerable utility particularly in the southern pine region where *P. gigantea* is the major decay fungus in pine pulpwood, stored logs, and poles and pilings on the seasoning yard. The reagent has not been found useful as a general indicator of decayed wood, however, because wood species vary in pH and decay fungi differ widely in the extent to which they increase the acidity of wood.

## Experiments with Osmium Tetroxide

During a recent electron microscope investigation on the influence of white- and brown-rot fungi on wood cell walls, it was observed that sweetgum sapwood decayed by the brown-rot fungus, *Poria monticola*, became darkened by the fixative-stain, osmium tetroxide, much more rapidly than sound wood. This observation led to trials of this reagent as a general indicator for decayed wood.

Various wood samples decayed in the laboratory by pure cultures of known fungi were tested. A 1-percent (weight/volume) aqueous solution of osmium tetroxide was applied to a fresh-cut surface of each sample with a pipette. The time necessary for development of a jet black color (osmium tetroxide reduced to black metallic osmium) was noted as short (less than 5 minutes) or long (more than 20 minutes).

The results of these trials, as reported in Table 1, show that osmium tetroxide reacted in less than 5 minutes with wood decayed by all the brown-rot fungi tested. Samples of wood decayed by *Poria monticola* darkened

**Table 2.—TIME REQUIRED TO STAIN UNDECAYED HEARTWOOD SAMPLES OF NORTH AMERICAN SOFTWOODS[1]**

More than 20 minutes (Long)

*Abies amabilis*, Pacific silver fir
*Abies balsamea*, balsam fir
*Abies concolor*, white fir
*Abies fraseri*, Fraser fir
*Abies grandis*, grand fir
*Abies magnifica*, California red fir
*Abies procera*, noble fir
*Chamaecyparis lawsoniana*, Port-Orford-cedar
*Chamaecyparis nootkatensis*, Alaska-cedar
*Chamaecyparis thyoides*, Atlantic white-cedar
*Cupressus arizonica*, Arizona cypress
*Juniperus deppeana*, alligator juniper
*Juniperus monosperma*, one-seed juniper
*Juniperus occidentalis*, western juniper
*Juniperus osteosperma*, Utah juniper
*Juniperus scopulorum*, Rocky Mountain juniper
*Juniperus silicicola*, southern redcedar
*Juniperus virginiana*, eastern redcedar
*Larix laricina*, tamarack
*Libocedrus decurrens*, incense-cedar
*Picea glauca*, white spruce
*Picea mariana*, black spruce
*Picea pungens*, blue spruce
*Picea rubens*, red spruce
*Picea sitchensis*, Sitka spruce
*Pinus attenuata*, knobcone pine
*Pinus banksiana*, jack pine
*Pinus clausa*, sand pine
*Pinus contorta*, lodgepole pine
*Pinus echinata*, shortleaf pine
*Pinus edulis*, pinyon
*Pinus elliottii*, slash pine
*Pinus engelmannii*, Apache pine
*Pinus flexilis*, limber pine
*Pinus glabra*, spruce pine
*Pinus jeffreyi*, Jeffrey pine
*Pinus lambertiana*, sugar pine
*Pinus monophylla*, singleleaf pinyon
*Pinus monticola*, western white pine
*Pinus palustris*, longleaf pine
*Pinus ponderosa*, ponderosa pine
*Pinus resinosa*, red pine
*Pinus rigida*, pitch pine
*Pinus sabiniana*, Digger pine
*Pinus serotina*, pond pine
*Pinus strobus*, eastern white pine
*Pinus taeda*, loblolly pine
*Pinus virginiana*, Virginia pine
*Taxodium distichum*, baldcypress
*Thuja occidentalis*, northern white-cedar
*Thuja plicata*, western redcedar
*Tsuga canadensis*, eastern hemlock
*Tsuga heterophylla*, western hemlock
*Tsuga mertensiana*, mountain hemlock

Less than 5 minutes (Short)

*Larix occidentalis*, western larch
*Pseudotsuga menziessi*, Douglas-fir
*Sequoia gigantea*, giant sequoia
*Sequoia sempervirens*, redwood
*Taxus brevifolia*, Pacific yew

[1]Sapwood samples of the respective species required 20 minutes or more in all instances.

**Table 3.—TIME REQUIRED TO STAIN UNDECAYED HEARTWOOD SAMPLES OF NORTH AMERICAN HARDWOODS[1]**

More than 20 minutes (Long)

*Acer saccharinum*, silver maple
*Aesculus glabra*, Ohio buckeye
*Aesculus octandra*, yellow buckeye
*Alnus rhombifolia*, white alder
*Betula alleghaniensis*, yellow birch
*Betula papyrifera*, paper birch
*Betula populifolia*, gray birch
*Carya aquatica*, water hickory
*Carya cordiformis*, bitternut hickory
*Carya glabra*, pignut hickory
*Carya illinoensis*, pecan
*Carya laciniosa*, shellbark hickory
*Carya ovata*, shagbark hickory
*Carya tomentosa*, mockernut hickory
*Celtis laevigata*, sugarberry
*Celtis occidentalis*, hackberry
*Cornus nuttallii*, Pacific dogwood
*Diospyros virginiana*, common persimmon
*Fraxinus americana*, white ash
*Fraxinus latifolia*, Oregon ash
*Fraxinus nigra*, black ash
*Fraxinus pennsylvanica*, green ash
*Fraxinus profunda*, pumpkin ash
*Fraxinus quadrangulata*, blue ash
*Ilex opaca*, American holly
*Liquidamber styraciflua*, sweetgum
*Liriodendron tulipifera*, yellow-poplar
*Maclura pomifera*, Osage-orange
*Magnolia acuminata*, cucumbertree
*Magnolia grandiflora*, southern magnolia
*Magnolia virginiana*, sweetbay
*Nyssa aquatica*, water tupelo
*Nyssa aecche*, Ogeechee tupelo
*Nyssa sylvatica*, black tupelo, blackgum
*Platanus occidentalis*, American sycamore
*Populus balsamifera*, balsam poplar
*Populus deltoides*, eastern cottonwood
*Populus fremontii*, Fremont cottonwood
*Populus grandidentata*, bigtooth aspen
*Populus heterophylla*, swamp cottonwood
*Populus tremuloides*, quaking aspen
*Populus trichocarpa*, black cottonwood
*Salix amygdaloides*, peachleaf willow
*Sassafras albidum*, sassafras
*Tilia caroliniana*, Carolina basswood
*Tilia heterophylla*, white basswood
*Ulmus americana*, American elm
*Ulmus rubra*, slippery elm
*Ulmus thomasii*, rock elm

Less than 5 minutes (Short)

*Acer macrophyllum*, big leaf maples
*Acer negundo*, box elder
*Acer nigrum*, black maple
*Acer rubrum*, red maple
*Acer saccharum*, sugar maple
*Alnus rubra*, red alder
*Betula lenta*, sweet birch
*Betula nigra*, river birch
*Castanea dentata*, American chestnut
*Castanopsis chrysophylla*, golden chinkspin
*Cornus florida*, flowering dogwood
*Fagus grandifolia*, American beech
*Gleditsia triacanthos*, honeylocust
*Juglans cinerea*, butternut
*Juglans nigra*, black walnut
*Lithocarpus densiflorus*, tanoak
*Morus rubra*, red mulberry
*Ostrya virginiana*, eastern hophornbeam
*Prunus serotina*, black cherry
*Quercus agrifolia*, California live oak
*Quercus alba*, white oak
*Quercus arizonica*, Arizona white oak
*Quercus bicolor*, swamp white oak
*Quercus chrysolepis*, canyon live oak
*Quercus coccinea*, scarlet oak
*Quercus douglasii*, blue oak
*Quercus ellipsoidalis*, northern pin oak
*Quercus emoryi*, Emory oak
*Quercus falcata*, southern red oak
*Quercus gambelii*, Gambel oak
*Quercus garryana*, Oregon white oak
*Quercus kelloggii*, California black oak
*Quercus laevis*, turkey oak
*Quercus laurifolia*, laurel oak
*Quercus lobata*, California white oak
*Quercus lyrata*, overcup oak
*Quercus macrocarpa*, bur oak
*Quercus marilandica*, blackjack oak
*Quercus michauxii*, swamp chestnut oak
*Quercus muehlenbergii*, chinkapin oak
*Quercus myrtifolia*, myrtle oak
*Quercus nigra*, water oak
*Quercus nuttallii*, Nuttall oak
*Quercus palustris*, pin oak
*Quercus phellos*, willow oak
*Quercus prinus*, chestnut oak
*Quercus rubra*, northern red oak
*Quercus stellata*, post oak
*Quercus velutina*, black oak
*Quercus virginiana*, live oak
*Robinia pseudoacacia*, black locust
*Tilia americana*, American basswood
*Umbellularia californica*, California-laurel

[1]Sapwood samples of the respective species required 20 minutes or more in all instances.

[4] Lindgren, R. M. Color Test for Early Storage Decay in Southern Pine. U. S. Forest Products Laboratory Report No. 2037, 1955.

with equal rapidity at stages of decay ranging from incipient (2 percent weight loss) to advanced (70 percent weight loss). The reagent reacted in 20 minutes or more (often approaching 2 hours) with all samples infected with white-rot fungi and with undecayed samples of the same wood species.

The reagent was also tested in the field. Fresh as well as dry specimens decayed by unidentified fungi, but showing typical symptoms of brown rot (brown coloration, cubical checking pattern, brashness) darkened in less than 5 minutes. Field collections of obviously white-rotted wood, compression wood, tension wood, as well as samples infected with blue-stain fungi, darkened after 20 minutes or more. The reaction worked equally well on a number of hardwoods and softwoods. Long pieces showing a transition from advanced stages of brown rot to apparently sound wood showed a rather abrupt transition from fast to slow darkening zones after streaking with the reagent. Figure 1 shows a sample of brown-rotted wood before and after treatment for 5 minutes with osmium tetroxide.

To ascertain whether sound wood of any species would react rapidly with the reagent, it was also applied to the undecayed sapwood and heartwood of a wide selection of North American timber species. The results of these trials are shown in Tables 2 and 3. The reagent reacted in 20 minutes or more with the sapwood of all the species tested, but the heartwood of 5 softwood species and a number of hardwoods blackened in less than 5 minutes. For this reason the reagent cannot be used to detect brown rot in the heartwood of these few exceptional species. This finding does not influence the usefulness of the method for detecting brown rot in sapwood or in the heartwood of the other species listed in Table 2.

### Recommended Procedure

On the basis of these observations, the following procedure for the preparation and use of osmium tetroxide as a stain for the identification of brown-rotted wood is suggested. Remove the label from a 1-gram ampule of osmium tetroxide by soaking the label in warm water and scraping it with a razor blade. Immerse the ampule in hot water to melt the osmium tetroxide. After scoring the ampule with a file, place it in a thick-walled, glass-stoppered bottle and break the ampule by striking it with a glass rod. Add 100 milliliters of water. Dissolve the reagent by shaking after carefully stoppering the bottle.[5] The reagent should be stored in a brown bottle in a refrigerator to minmize color development. A medicine dropper bottle with a screw cap is especially convenient for application of the reagent to wood samples and for safe handling in the field.

If the sample in question is of heartwood, consult Tables 2 and 3 to insure that undecayed wood of that species does not react rapidly with the reagent. Then apply a few drops of the reagent to a fresh-cut surface. If the treated wood becomes blackened in 5 minutes or less, it is considered to have been decayed by a brown-rot fungus.

### Uses for the Method

Osmium tetroxide may be especially useful for the detection of brown rot in wood structures, storage piles of pulpwood, logs, poles, piling, ties, and other wood products. The early detection of brown rot is especially important in stored pulpwood since pulp yields and quality are reduced much more rapidly by brown-rot than white-rot fungi. This is due to the ability of brown-rot fungi to more rapidly consume the wood carbohydrates and to reduce the average degree of polymerization of the cellulose remaining after various stages of decay.[6]

No effort has been made to determine the nature of the substances in brown-rotted wood that cause the reagent to react more rapidly with it than with sound wood.

[5] Osmium tetroxide is a fixative for plant and animal tissues and is therefore highly toxic. Its vapor will damage the eyes and mucous membranes. For these reasons, an open bottle of the solution should not be held near the face. Contact with the skin or inhalation of osmium fumes should be avoided by preparing the reagent in a force draft hood or in a very well ventilated room.

[6] Cowling, E. B. Comparative Biochemistry of the Decay of Sweetgum Sapwood by White- and Brown-Rot Fungi. U. S. Department of Agriculture Technical Bulletin. In Press.

# Utilization of Manpower[1]

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PETER DRUCKER SAYS, "THE success, and ultimately the survival of every business, large or small, depends in the last analysis on its ability to develop people." I can't help but agree with him.

Isn't it true that your competitors can obtain raw materials for about the same price that you can? It seems that wage rates are rapidly being equalized in our industry so your competitor has no advantage. You and your competitor pay about the same for power, for taxes and for transportation. Your competitor has the same type of tools and equipment in use as you have. The advantage of a patent or a secret process is short lived. Keen engineers and sharp lawyers quickly find a way around them. As a result, the competitive advantage in these and similar areas is small.

Thus, the productivity of people remains as the one area with the greatest opportunities for developing competitive advantage. Some authorities claim that the great majority of employees have not reached the halfway mark when it comes to using the skill, know-how and ability which they command. These same authorities assert that most persons are capable of producing at 80 percent of capacity without undue strain. The area between the 50 percent and 80 percent represents an important profit potential. When we recognize that many jobs require only 20 percent to 30 percent of a person's capacity, the profit potential becomes greater. How to ultilize the potentials of the people that make up its work force is a challenge for all management today.

### What Can Be Done?

What can we do to narrow the gap between what can be done and what is being done? One of the things that can be done is to select people that fit the job and have the skills, aptitudes and ability to do the job—put square pegs in square holes. This is becoming increasingly true as we move out of the "muscle" age into the

[1] Presented at the Wood Industries Conference, Portland, Oregon, September 10, 1[illegible]. Recommended for publication, March, 19[illegible].

# Challenge for Management: To remain profitable and competitive in the forest products industry, you must utilize all the skills, aptitudes, and capacities of your people to the fullest extent.

missile" age—an age that demands kill, know-how and brain-power, not ust brute strength.

Modern businessmen cannot afford o be guided by a rule-of-thumb ethod in selecting personnel. We nust devise the best possible selection procedure for our operations so we can obtain those employees who will be of the greatest value in the organization.

A man I know wanted to make his fortune in the sawmilling business. He was bright enough to realize he had better find out if there was a source of raw material available and the size and type. One fact he gathered was that the maximum-sized log was 30 inches in diameter. With that fact in mind he designed a mill on the basis of installing a 30-inch circular saw. You know what happened when he tried to saw that first 30-inch log.

This may sound fantastic, but not so fantastic as the thousands of people in industry whose qualifications do not match the requirements of the jobs they hold.

I am sure that you would not select a 30-inch circular saw to mill a 30-inch log or buy a trimmer to do the job of a planer. But how about this area of people? Are your selection procedures well thought out? Are you putting the square pegs in the square holes?

### Investments in Employees

The average working life of an employee is generally a period ranging from 25 to 40 years. During this time the employee will be paid at least an average of $100,000.00 in direct wages, welfare and retirement benefits. I am sure that an investment of this size into a new piece of equipment or into a new product would be closely scrutinized and given a great deal of consideration. Yet, investments of this amount are made in newly-hired employees every day, but do you scrutinize as closely and give as much consideration to the selection of personnel as you do to the selection of machines?

For example: if a foreman in your unit came into the office some evening at 4:30 p.m. and said, "I just ran the forklift out on the salvage pile—I need a new forklift tomorrow morning." Would you see that he had the forklift the next morning? Of course not.

The request probably would go through many channels. A number of questions would be asked and much thought given to the purchase before the request ended up on the purchasing agent's desk. It would then still take anywhere from one week to a month before the foreman received the new forklift.

But how many times does a foreman come into the office and say, "I need 'X' number of men tomorrow morning," and everyone shakes his head and runs helter skelter trying to find 'X' bodies to fill the request.

### The Right Perspective

Maybe that's good business, but I wonder if we are putting people in the right perspective when we spend a great deal of time and effort of management people determining whether a piece of machinery costing $3,000 should be purchased, and then attempt to hire men on an hour's notice in whom we will eventually have $100,000 invested.

These are men who will control your production and maintenance cost —who will determine the quality and quantity of your finished product—who will affect your turnover, your accident frequency and severity rates —who will have an effect upon your payroll taxes for unemployment compensation and social security—who will affect the cost of any company-paid insurance. These are men who control all of the costs that determine whether you have an edge on the competition . . . whether you have a profitable business.

Have you ever calculated what rule-of-thumb selection procedures cost you in all these areas? Have you ever given an hour's concentrated thought to how much it costs you when you hire an eight-ball or misfit, or transferred a man to another job where he may become a misfit because he does not have the skills and ability to do the job effectively?

### Physical Makeup

Let's take a look at one specific area of human capacity and the utilization of that capacity—the physical makeup of the employee. Have you ever given any thought to the height of the individual in relation to his work?

In one case that I know of a number of people working on a specific machine developed bad backs. After a period of time someone stumbled onto the fact that each of these persons was over 5 feet 8 inches tall. They found that in the group of people who were less than 5 feet 8 inches tall there was no incidence of backache or strain.

It would appear to me with this knowledge that we would be foolish to hire or place people on this job who were over 5 feet 8 inches tall, not only from the viewpoint of the cost of occupational insurance but also from the viewpoint of productivity.

At one of our branches we had an employee who had had 11 accidents. The personnel manager of this branch became quite concerned about what might happen to the man if he had the 12th accident. The odds invited a major disabling accident.

The personnel manager called the man in to have a chat with him. After the interview the employee was given some skill tests. The tests showed that the man had no hand and eye coordination. Anyone familar with the sawmill industry can imagine the problems an employee with this type of a physical handicap would have in running a piece of sawmill machinery. No wonder he had had 11 accidents. Certainly under those conditions we were not utilizing that man's skills and capacities in the most effective or profitable manner.

This is only one area, the factor of physical capacity. There are many other factors that affect a man's effectiveness on a job—his mental abilities and aptitudes; his vocational interests; his knowledge, skill and judgment; motivational needs; emotional maturity; personal and social attitudes; work habits; and personal characteristics.

And, whether a man is productive or marginal has a decisive effect upon whether we can remain profitable and competitive in the industry.

### Summary

In this age when every business is looking for a competitive advantage, the difference between what can be done and what is being done is the acre of diamonds that needs to be tilled and cultivated. Selecting people whose qualifications match the requirements of the job and utilizing the person's skills, aptitudes and capacities are challenges facing all management today.

# Collapse and Its Removal

## IN PACIFIC MADRONE[1]

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**Reconditioning treatments resulted in excellent recovery from collapse and warp in Pacific madrone that had been kiln dried at relatively high temperatures. Specific recommendations are given for treatments that will produce high-quality lumber.**

PACIFIC MADRONE (*Arbutus menziesin Pursh*) in a relatively abundant hardwood species of the west coast of the United States where there are an estimated 1.6 billion board feet of standing saw timber on commercial forest land. The wood is very attractive, and seems to be well suited for face veneer, solid furniture stock, flooring material, and other high quality uses (11).[2] Mainly because of seasoning difficulties, however, its commercial use has mostly been limited to firewood and charcoal production. Several workers (1, 2, 12, 14) have attempted to develop satisfactory drying techniques for Pacific madrone, generally with the same results—the species can be dried without serious degrade due to surface checking, but warpage and abnormal shrinkage seem to be unavoidable. The problem of warp can be somewhat reduced by avoiding crooked logs and by using proper sawing techniques. Espenas (2) suggests the use of heavy weights on the kiln charge to reduce the degree of warp. However, these various precautions do not reduce the extent of warp to a generally acceptable level. Aside from crookedness of grain, the problem of warp hinges on the occurrence of differential shrinkage and collapse in the material. Therefore, if collapse could be either avoided or removed from the dried material, the seasoning problem in madrone would be eliminated or greatly reduced, thereby making the species available for high quality usage. This study followed an investigation on the drying characteristics of Pacific madrone (1) during which exploratory tests were conducted to determine the feasibility of removing collapse through a recovery treatment known as reconditioning. The results of the tests were encouraging, and showed much promise of producing collapse-free, warp-free madrone lumber.

Reconditioning is a simple process, consisting only of a prolonged exposure of material to saturated steam at high temperatures. The treatment can often be used to remove or greatly reduce collapse and other distortion. The process was accidently and independently discovered by J. Grant and E. Grant of Victoria, Australia, sometime before 1921. Its value was not recognized until 1921–1922 when H. D. Tiemann carried out further experimental investigations while visiting in Australia. Since that time, the process has developed into a standard commercial practice in that country.

The most commonly accepted theory on the mechanism of reconditioning is that the high temperature combined with the moisture in the wood softens or temporarily plasticizes the wood substance and allows the distorted cells to resume their natural shape. It is not known why the plasticized cells react in this manner. Thus far, theories on their behavior have been speculative and not based on experimental evidence.

A number of factors influence the amount of dimensional recovery which can be obtained in collapsed wood by the reconditioning treatment. The most important of these are: the moisture content of the material at the time of reconditioning; the maximum kiln temperature to which the material had been exposed before treatment; and the temperature maintained during treatment. Greenhill (3) showed that the treatment is most effective for Australian timbers when the material is reconditioned at a moisture content of 15 to 20 percent. The amount of recovery was sharply reduced when moisture content levels were below 15 percent. It was also shown that the amount of recovery decreased as the maximum kiln temperature increased. Optimum recovery and minimum treatment time are attained when the material is treated at 212° F.

The exploratory tests conducted during, the drying of madrone (1) included reconditioning tests on material with moisture contents ranging from 8 to 20 percent. The maximum kiln temperatures to which the material had been exposed before treatment ranged from 120° F. to 180° F. The reconditioning temperature was held at 212 F. for all tests. In contrast to the results obtained in Australia, it appeared that collapse recovery in madrone is best when the treatment is performed at the relatively low moisture level of 8 to 12 percent. Also, excellent recovery was obtained in the material which had been exposed to high kiln temperatures.

Sixty percent of the logs used as a material source for the drying investigation (1) had dark red zones in the heartwood. The zones were centered around the pith of each log in an irregular fashion, and comprised approximately 10 to 40 percent of the total heartwood volume. The material from these zones (referred to in this paper as red heartwood) seemed especially prone to collapse, and did not respond so well to the reconditioning treatment as did the plain heartwood.

The present study was undertaken to establish the relationships between collapse recovery in madrone and the various factors by which it is influenced and to suggest specific recommendations for the most effective reconditioning procedure.

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[2] Numbers in parentheses refer to Literature Cited at the end of this report.

## Procedure

**Experimental Design:** Four variables were considered: 1) moisture content at the time of reconditioning; 2) growth-ring orientation; 3) heartwood type; and 4) maximum kiln temperature before treatment. Three moisture content levels were included, with nominal values of 18, 13, and 8 percent. Each specimen initially had a length of 12 inches parallel to the grain, and a cross section of 1 by 4 inches. Two growth-ring orientations, tangential and radial, were included where the width dimension of the specimen corresponded to directions parallel and perpendicular to the growth rings, respectively. The two heartwood types, red and plain, were included. All possible combinations of the first three variables gave a total of 12 specimen types. Four replications of each type were exposed to a maximum kiln temperature of 160° F. for 24 hours before the reconditioning treatment. Two replications of each of the eight specimen types included in the two lower moisture content levels were exposed for 96 hours to a maximum kiln temperature of 180° F. before treatment.

**Specimen Preparation:** The specimens, 4 by 12 inches, were selected from 4/4 boards sawn from twelve 8-foot logs representing 10 trees from the Jackson State Forest in Mendocino County, California. Surfaced boards were used to facilitate the selection of proper growth-ring orientation and to give smooth surfaces for shrinkage measurements. The specimens were end-coated with a rubber-based resin before they were dried.

The material was dried in a 500-board-foot capacity experimental drykiln, according to a schedule similar to that derived during the drying study which preceded this investigation (1). The kiln was set initially to have a dry-bulb temperature of 120° F. with a wet-bulb depression of 3° F. All specimens were dried under the same kiln conditions until their average moisture content reached 20 percent. At that stage, the total drying time was 7 days, and the material had been exposed to a maximum kiln temperature of 160° F. for 24 hours. The specimens to be reconditioned at 18 percent moisture content were then removed from the kiln. The remaining specimens were dried in two groups. Those that were to be exposed to a maximum kiln temperature of 160° F. were dried to their appropriate moisture content with a dry-bulb temperature of 130° F. The lowered temperature was used in order to keep the time of exposure to the maximum temperature constant for all of the material from the different moisture content levels. The remaining specimens were dried to their appropriate moisture content levels with a dry-bulb temperature of 180° F. All specimens were conditioned for 1 week, before being reconditioned, in controlled humidity rooms with appropriate equilibrium moisture content conditions. At the end of that period, the average moisture gradients between shell and core were 6.8, 2.7, and 2.0 percent respectively, for material of nominal moisture content values of 18, 13, and 8 percent. The actual moisture content values of the 3 groups averaged 18.9, 13.6, and 9.2 percent.

Just before the reconditioning treatments, ¾-inch sections were sawn from each end of each specimen and used to determine the specimens' exact moisture content. The remaining central 6-inch portion of each specimen was end-coated and used for the reconditioning tests.

**Reconditioning Procedure:** The reconditioning treatments consisted of 4-hour exposure to saturated steam in an autoclave maintained at atmospheric pressure and a temperature of 212° F. The material was treated in groups of 4 to 6 specimens which rested in the autoclave chamber free of restraint.

To determine the length of time necessary for efficient reconditioning, the autoclave was equipped with a device that made possible continuous or periodic width-recovery measurements to the nearest 0.001 inch without interruption of the treatment. Essentially, the device consisted of a dial indicator rigidly fixed in a position outside the autoclave chamber. The indicator was equipped with an extended probe that entered the chamber through a guide sleeve. The specimen rested, in alignment with the probe, on a rack equipped with a stop that forced the expansion to occur toward the indicator. As collapse recovery occurred, the specimen increased in width and thus activated the dial indicator. To avoid error resulting from thermo-expansion of the probe and specimen rack, the system was heated to the operating temperature before reconditioning was started. During the course of the treatments, recovery readings were taken at intervals convenient for plotting recovery—time curves. Curves were obtained for 12 specimens representing each combination of the variables.

After reconditioning, all specimens were dried to 8 percent moisture content in the kiln at a dry-bulb temperature of 180° F.

Width and thickness of each specimen were measured at marked points during the green condition, periodically during drying, immediately before reconditioning, immediately after reconditioning, and finally at 8 percent moisture content. The measurements, made with a dial indicator to the nearest 0.001 inch, were used to calculate shrinkage as a percent of the green dimension.

## Results and Discussion

Radial and tangential shrinkage valves obtained immediately before reconditioning, immediately after reconditioning, and at 8 percent moisture content after reconditioning are given in Tables 1 and 2. The values in Table 1 are for the specimens that had been exposed to a maximum kiln temperature of 160° F.; those in Table 2 are for the material exposed to a maximum temperature of 180° F. prior to reconditioning. Each figure in the two tables represents the average percentage of shrinkage of all replications within the various specimen types. Since the final shrinkage at 8 percent moisture content is likely to be of the most practical interest, those values were used, instead of the recovery during reconditioning, in evaluating effectiveness of the treatment. All of the shrinkage values used to obtain

**Table 1.—SHRINKAGE DATA FOR MATERIAL EXPOSED TO 160°F. MAXIMUM KILN TEMPERATURE**

| Specimen type | Nominal moisture content before treatment (percent) | Shrinkage (percent of green dimension)* Radial: Before treatment | Radial: After treatment | Radial: at 8 percent M.C. | Tangential: Before treatment | Tangential: After treatment | Tangential: at 8 percent M.C. |
|---|---|---|---|---|---|---|---|
| Flat-sawn boards, Red Heartwood | 18 | 14.9** | 4.8 | 12.7 | 17.8 | 10.4 | 16.6 |
| | 13 | 18.9 | 5.7 | 10.4 | 19.1 | 6.4 | 11.0 |
| | 8 | 16.9 | 4.8 | 8.3 | 21.0 | 8.7 | 12.3 |
| Quarter-sawn boards, Red Heartwood | 18 | 8.6 | 2.2 | 5.9 | 24.2 | 10.0 | 16.0 |
| | 13 | 17.2 | 5.3 | 8.9 | 33.9 | 8.6 | 14.3 |
| | 8 | 17.1 | 7.8 | 10.3 | 28.2 | 8.6 | 12.0 |
| Flat-sawn boards, Plain Heartwood | 18 | 9.2 | 3.1 | 6.1 | 11.2 | 3.7 | 8.3 |
| | 13 | 12.8 | 1.2 | 4.2 | 12.1 | 2.0 | 3.5 |
| | 8 | 8.8 | 1.2 | 3.2 | 15.2 | 2.9 | 5.8 |
| Quarter-sawn boards, Plain Heartwood | 18 | 6.9 | 2.9 | 6.3 | 17.6 | 8.9 | 13.4 |
| | 13 | 8.7 | 1.3 | 4.1 | 16.8 | 3.4 | 7.1 |
| | 8 | 9.4 | 2.2 | 4.1 | 18.7 | 4.3 | 6.7 |

*Each figure represents the average shrinkage of 4 specimens.
**Radial shrinkage corresponds to shrinkage in thickness in flat-sawn boards and to shrinkage in width in quarter-sawn boards. The opposite is true for tangential shrinkage figures.

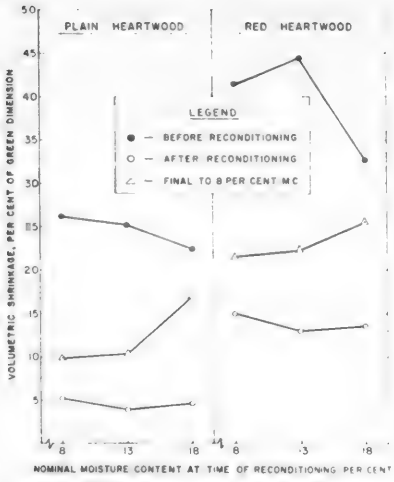
PLAIN HEARTWOOD
RED HEARTWOOD
LEGEND
● — BEFORE RECONDITIONING
○ — AFTER RECONDITIONING
△ — FINAL TO 8 PER CENT M.C.
VOLUMETRIC SHRINKAGE, PER CENT OF GREEN DIMENSION
NOMINAL MOISTURE CONTENT AT TIME OF RECONDITIONING, PER CENT

**Fig. 1.—Variation of volumetric shrinkage at various stages with moisture content at time of reconditioning. (Each point represents the average shrinkage of 8 specimens.)**

the average figures at 8 percent moisture content were statistically analyzed to determine which of the variables considered have a significant effect on the final shrinkage.

**Effect of Heartwood:** An analysis of variance was performed with the data represented in Table 1 to test the significance of the effect on final shrinkage of heartwood type, growth-ring orientation, moisture content, and their interactions, if any. To avoid complications resulting from possible effect of size on one-dimensional shrinkage, the analysis was first based on estimates of volumetric shrinkage. The values were estimated by summing the final shrinkages in width and thickness for each specimen.[3] Results of the analysis are shown in Table 3. Variations resulting from both heartwood type and moisture content at the time of treatment are highly significant; those resulting from growth-ring orientation and interactions between variables are not significant. The average volumetric shrinkage present before reconditioning, after reconditioning, and at 8 percent moisture content is plotted against moisture content at time of reconditioning in Figure 1. Volumetric shrinkage values for flat-sawn and quarter-sawn material were grouped together in the figure since the effect of growth-ring orientation was shown not to be significant. The effect of type of heartwood is clearly seen in Figure 1. The final shrinkage to 8 percent moisture content in the red heartwood is much higher than that for the plain heartwood. The effect is most pronounced in the material reconditioned at the two lower moisture content levels. There, the final volumetric shrinkage in the red heartwood is more than twice as great as that in the plain heartwood. Two factors very likely contributed to these differences between heartwood types. First, the average green moisture content of the red heartwood was 8.7 percent higher than that of the plain heartwood (100.2 percent as compared with 91.5 percent). It has been stated (5) that collapse is often associated with wet zones within material. This can be explained on the basis of Tiemann's "liquid tension" theory on collapse (13) since cells within wet zones are more likely to be fully saturated. Second, the red heartwood contained large amounts of extractive material. Other investigators have found that collapsed material often possessed colored substances which were not present in adjacent material which did not collapse (5). It is probable that the two factors are in some way related.

[3] It can be shown (6) that only a very small error is encountered in using the sum of the shrinkages in width, thickness, and length as an estimate of volumetric shrinkage. Since shrinkage in length is small compared with that of the other dimensions, the estimates used in the analysis are sufficiently accurate for comparison purposes.

**Effect of Moisture:** The effect of moisture content can also be seen in Figure 1. The final shrinkage at 8 percent moisture content is decreased as the moisture content at time of reconditioning is decreased, the effect being most pronounced between the 18 and 13 percent levels. It is unlikely that the difference between the two lower moisture content levels is statistically significant. By observing, in Figure 1, the differences between the ordinates of points representing shrinkage after reconditioning and at 8 percent moisture content, it appears that differences encountered between reconditioning moisture content levels are the result of abnormal shrinkage occurring in the material of high moisture content during final drying. It is probable that the reoccurrence of abnormal shrinkage in this material can be attributed to compression set caused by severe drying stresses. This can be understood by considering the condition of the material immediately after reconditioning. The gain in moisture in the outer layers is more than sufficient to eliminate the moisture gradient present before reconditioning. With a gain of approximately 6 percent moisture content during the treatment, the boards reconditioned at the high moisture content level will contain approximately 24 percent moisture, distributed quite uniformly within the material. It will be shown later that reconditioned material is essentially stress-free. From these considerations, it follows that, at the start of final drying, the boards could be considered analogous to green material possessing 24 percent moisture. From this, it is reasonable to assume that the 180° F. dry-bulb temperature used for final drying could cause abnormal shrinkage in the form of compression set.

Figure 1 shows that the shrinkage immediately after reconditioning is least in the material treated at 13 per cent moisture content. For the boards reconditioned at 8 percent moisture content, shrinkage is expected to be higher because the material is subject to a greater amount of normal shrinkage. The reverse is expected for the material treated at 18 percent moisture content, but such is not the case. This indicates that the reconditioning treatment is less effective in eliminating abnormal shrinkage when the material is treated at the high moisture content level. Assuming that the effect does exist, it can explain part of the difference encountered in final shrinkage among the three moisture content levels.

Table 1 shows that shrinkage before reconditioning is often not consistent with moisture content; i.e., the highest shrinkage is not always in the material having the lowest moisture content. The discrepancy is especially pronounced in the red heartwood (Fig. 1). The discrepancies are explained by the variability of the material rather than by drying technique since all of

**Table 2.—SHRINKAGE DATA FOR MATERIAL EXPOSED TO 180°F. MAXIMUM KILN TEMPERATURE**

| Specimen type | Nominal moisture content before treatment (percent) | Shrinkage (percent of green dimension)* Radial: Before treatment | Radial: After treatment | Radial: at 8 percent M.C. | Tangential: Before treatment | Tangential: After treatment | Tangential: at 8 percent M.C. |
|---|---|---|---|---|---|---|---|
| Flat-sawn boards, Red Heartwood | 13 | 20.0** | 9.4 | 12.4 | 19.3 | 10.0 | 13.5 |
| | 8 | 31.0 | 11.8 | 15.2 | 15.9 | 8.4 | 10.9 |
| Quarter-sawn boards, Red Heartwood | 13 | 9.6 | 5.1 | 7.9 | 28.4 | 16.6 | 21.0 |
| | 8 | 11.0 | 5.4 | 7.5 | 34.6 | 14.7 | 18.7 |
| Flat-sawn boards, Plain Heartwood | 13 | 11.2 | 2.9 | 5.4 | 14.0 | 3.4 | 6.8 |
| | 8 | 11.7 | 1.8 | 4.1 | 16.7 | 2.9 | 6.2 |
| Quarter-sawn boards, Plain Heartwood | 13 | 8.0 | 2.3 | 4.6 | 23.0 | 8.1 | 17.0 |
| | 8 | 12.0 | 3.2 | 5.5 | 21.8 | 4.2 | 6.9 |

*Each figure represents the average shrinkage of 4 specimens.
**Radial shrinkage corresponds to shrinkage in thickness in flat-sawn boards and to shrinkage in width in quarter-sawn boards. The opposite is true for tangential shrinkage figures.

the material was dried together. The high shrinkage level of the red heartwood at 13 percent moisture content before reconditioning (Fig. 1) is explained by two specimens that shrank well over 50 percent in volume.

Published shrinkage figures for mahrone dried to the oven-dry condition by ASTM methods are 11.9 and 5.4 percent for the tangential and radial directions, respectively (9). Assuming a fiber saturation point of 30 percent, at 8 percent moisture these figures would be 8.1 and 4.0 percent. It is interesting to note that many of the final shrinkage figures for plain heartwood in Table 1 are well below these values. The differences can be explained by either the presence of abnormal shrinkage in the published figures or a reduction in normal shrinkage caused by reconditioning. It is quite possible that both factors are present. A reduction in normal shrinkage could possibly be explained by the presence of tension set.

**Effect of Growth-Ring Orientation:** The radial and tangential shrinkage values represented in Table 1 were considered separately in two additional analyses of variance. The variables considered were the same as those in the previous analysis. Here, the effect of growth-ring orientation on final shrinkage was considered by testing the significance of differences encountered between width and thickness shrinkages for a given growth-ring direction. In this way, both tangential and radial shrinkages were tested for the existence of a size effect. The results of the analyses are given in Tables 4 and 5 for tangential and radial shrinkages, respectively. It is shown that the heartwood type has a highly significant influence on both radial and tangential shrinkage, as would be expected from the previous analysis. It is also shown that the effect of moisture content at the time of reconditioning is significant for tangential shrinkage but not for radial shrinkage. The reasons for the moisture effect in the tangential shrinkage are the same as those discussed above in relation to volumetric shrinkage. It is probable that the lack of a significant effect of reconditioning moisture content on final radial shrinkage can be explained by the resistance offered to shrinkage in this direction by the ray tissue. Assuming that this is the case, the severe drying stresses thought to be responsible for the moisture effect are largely resisted by ray tissue; consequently, the occurrence of compression set is not pronounced.

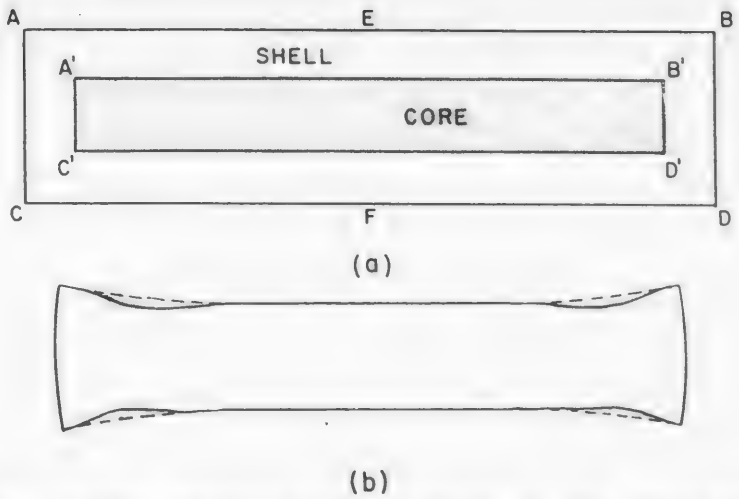


**Fig. 2.—Schematic representation of specimen crossections: (a) section showing idealized shell and core; (b) distorted section after drying. Shaded areas between broken and solid lines represent losses in crosssectional area resulting from compression set.**

Tables 4 and 5 show that growth-ring orientation within the specimen has a significant effect on the final shrinkage in the tangential but not in the radial direction. This can also be seen in Table 1. Final tangential shrinkage is greatest in the quarter-sawn material; i.e., tangential shrinkage is greater in thickness than in width. Similar effects have been found by other investigators (4, 10). Kauman (4) used a schematic representation of a cross-section similar to that shown in Figure 2a to describe how one-dimensional shrinkage is affected by board geometry.

During the first phase of drying, the shell material becomes stressed in tension as part of its shrinkage is resisted by the core. If the stresses become great enough, tension set occurs. Figure 2a shows that the tension set will occur throughout the width along AB and CD since the core will act as a column in resisting shrinkage in those directions. Resistance offered to shrinkage in thickness by the core in this manner occurs only at the edges along AC and BD. The shell material between A′B′ and C′D′ shrinks in thickness free of restraint. Shrinkage in thickness is increased further by the restrained shrinkage in the width direction, resulting from the "Poisson effect." As drying proceeds, the core begins to shrink, and gradually becomes stressed in tension as it is restrained by the shell. Again, the restraint is most pronounced in the width direction since the portions of shell between A′B′ and C′D′ act as columns to resist the movement of the core. These portions of the shell also serve as beams to resist a small amount of shrinkage in thickness which is again increased by the "Poisson effect" during this phase of drying. The above discussion demonstrates how the board geometry affects shrinkage in a given direction. It shows that shrinkage should be greater in thickness than in width for a given growth-ring direc-

**Table 3.—ANALYSIS OF VARIANCE OF FINAL VOLUMETRIC SHRINKAGE DATA[1]**

| Source | Degrees of freedom | Mean square | F-Ratio | Significance[2] |
|---|---|---|---|---|
| Heartwood | 1 | 1,368.54 | 53.95 | VS |
| Ring orientation | 1 | 8.76 | 0.35 | NS |
| Moisture content | 2 | 153.92 | 6.07 | S |
| Heartwood × ring orientation | 1 | 54.40 | 2.14 | NS |
| Heartwood × moisture content | 2 | 13.64 | 0.54 | NS |
| Ring orientation × moisture content | 2 | 10.74 | 0.42 | NS |
| Heartwood × ring orientation × moisture content | 2 | 52.50 | 2.07 | NS |
| Experimental error | 36 | 25.37 | 1.00 | |
| Total | 47 | | | |

[1] Final volumetric shrinkage values were estimated by summing the shrinkages width and thickness.
[2] NS—Not significant at 5 percent level of probability; S—significant at 5 cent level of probability; VS—significant at 1 percent level of probability.

**Table 4.—ANALYSIS OF VARIANCE OF FINAL TANGENTIAL SHRINKAGE DATA**

| Source | Degrees of freedom | Mean square | F-Ratio | Significance* |
|---|---|---|---|---|
| Heartwood | 1 | 423.64 | 53.04 | VS |
| Ring orientation | 1 | 35.71 | 4.47 | S |
| Moisture content | 2 | 97.67 | 12.23 | S |
| Heartwood × ring orientation | 1 | 9.36 | 1.17 | NS |
| Heartwood × moisture content | 2 | 0.92 | 0.11 | NS |
| Ring orientation × moisture content | 2 | 6.04 | 0.76 | NS |
| Heartwood × ring orientation × moisture content | 2 | 13.07 | 1.64 | NS |
| Experimental error | 36 | 7.99 | 1.00 | |
| Total | 47 | | | |

*NS—not significant at 5 percent level of probability; S—significant at 5 percent level of probability; VS—significant at 1 percent level of probability.

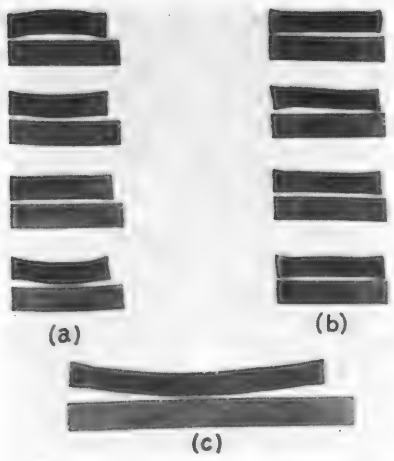


Fig. 3.—Matched sections from representative plain heartwood specimens before and after reconditioning: (a) flat-sawn material; (b) quarter-sawn material; (c) sections from an 11-inch board showing effect of reconditioning on wide material.

tion, a finding which is in agreement with the results of the present study.

**Effect of Temperature:** The effect of prolonged exposure to high kiln temperatures on final shrinkage was considered in an analysis of variance which tested the data represented in Table 2 against the data for the two corresponding moisture content levels represented in Table 1. Again, estimates of volumetric shrinkages were used. Since only two replications of the specimen types were exposed to the high kiln temperature, two of the four replications exposed to the lower kiln temperature were randomly eliminated to give a uniform sample for the analysis. Since the first analysis (Table 3) showed that growth-ring orientation does not have a significant effect on volumetric shrinkage, flat-sawn and quarter-sawn specimens were grouped together. Results of the analysis are given in Table 6. It is shown that the maximum kiln temperature to which the material has been exposed prior to the reconditioning treatment has a highly significant influence on final shrinkage. While the collapse-recovery treatment was very effective for all of the material, the final shrinkage was consistently greater in material that had been subjected to the high kiln temperature for a prolonged period before reconditioning. This is true even though the absolute recovery during reconditioning was highest in that material, since it possessed a greater amount of abnormal shrinkage before treatment. The apparent existence of abnormal shrinkage after the treatment indicates that the high kiln temperature inhibits complete recovery to some extent. Table 6 shows no significant difference in final shrinkage between the material reconditioned at 13 and at 8 percent moisture content.

**Reduction of Warp and Other Distortion:** The results and analyses discussed above demonstrate how shrinkage in madrone is remarkably reduced by the reconditioning treatment, but they do not indicate how the degree of warp is affected. The effect of reconditioning on both collapse and warp is illustrated in Figures 3 and 4. Cross sectional wafers representing the various specimen types are pictured in pairs. The upper wafer in each pair was sawn from the specimen just before treatment, while the lower wafers were taken from the pieces after they had been reconditioned and dried to 8 percent moisture content. In most cases, warp in the plain heartwood specimens (Fig. 3) was either eliminated completely or reduced to a very small amount. Although the warp recovery was seldom complete in the red heartwood material (Fig. 4), in most cases the distortion was reduced to a level that is acceptable for many applications. The effect of reconditioning on shrinkage recovery is well illustrated in both figures. Recovery in flat-sawn material (Figs. 3a and 4a) is most noticeable in width, while that in quarter-sawn material (Figs. 3b and 4b) is most pronounced in thickness —in each case the direction of highest original shrinkage. A pair of wafers from an 11-inch board reconditioned during the drying investigation (1) are shown in Figure 3c to show the effect of the treatment on wide material. These sections demonstrate clearly the value of reconditioning.

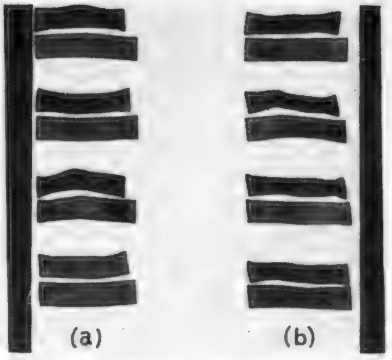


Fig. 4.—Matched sections taken from representative red heartwood specimens before and after reconditioning; (a) flat-sawn material; (b) quarter-sawn material.

Kauman (4) showed that the cross section shown in Figure 2a will have greater final shrinkage in thickness at the mid-section EF than at the edges AC and BD, because of the shrinkage restraint present at the edges. This explanation was offered to show why board faces are often "dished-in" after drying. In the present study it was found that, although thickness shrinkage is greater at the mid-section than at the edges, the most severe shrinkage in thickness occurs at positions near the edges in the vicinity of A′C′ and B′D′, as shown in Figure 2a. This occurrence is shown schematically in Figure 2b and can be seen in most of the specimens shown in Figures 3 and 4. It is believed that the high shrinkage at these zones can be explained by compression set. The tensile stresses present in the shell early in drying must be resisted by corresponding compressive stresses in the core. The tensile stresses present along AC and BD produce severe stresses in the core at A′C′ and B′D′, and cause compression set to occur in those zones. The set will be accentuated by any inherent tendency for the material to collapse, because a given stress will produce greater deformation in cells weakened by collapse. During further drying, shrinkage will occur throughout the core, and the final shrinkage in thickness will be greatest at the zones where the core was deformed by com-

Table 5.—ANALYSIS OF VARIANCE OF FINAL RADIAL SHRINKAGE DATA

| Source | Degrees of freedom | Mean square | F-Ratio | Significance* |
|---|---|---|---|---|
| Heartwood | 1 | 269.33 | 31.90 | VS |
| Ring orientation | 1 | 9.10 | 1.08 | NS |
| Moisture content | 2 | 6.77 | 0.80 | NS |
| Heartwood × ring orientation | 1 | 18.63 | 2.21 | NS |
| Heartwood × moisture content | 2 | 8.43 | 1.00 | NS |
| Ring orientation × moisture content | 2 | 22.34 | 2.65 | NS |
| Heartwood × ring orientation × moisture content | 2 | 16.70 | 1.98 | NS |
| Experimental error | 36 | 8.44 | 1.00 | |
| Total | 47 | | | |

*NS—Not significant at 5 percent level of probability; VS—significant at 1 percent level of probability.

Table 6.—ANALYSIS OF VARIANCE OF FINAL VOLUMETRIC SHRINKAGE DATA

| Source | Degrees of freedom | Mean square | F-Ratio | Significance |
|---|---|---|---|---|
| Heartwood | 1 | 993.47 | 37.59 | VS |
| Moisture content | 1 | 27.94 | 1.06 | NS |
| Temperature | 1 | 287.40 | 10.87 | VS |
| Heartwood × moisture content | 1 | 18.76 | 0.71 | NS |
| Heartwood × temperature | 1 | 18.45 | 0.70 | NS |
| Moisture content × temperature | 1 | 19.07 | 0.72 | NS |
| Heartwood × moisture content × temperature | 1 | 2.70 | 0.10 | NS |
| Experimental error | 24 | 26.43 | 1.00 | |
| Total | 31 | | | |

*NS—Not significant at 5 percent level of probability; VS—significant at percent level of probability.

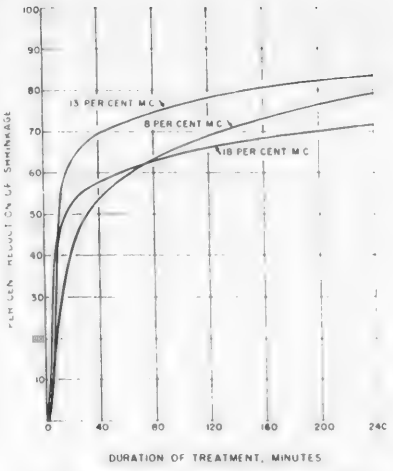


**Fig. 5.—Recovery-time curves showing shrinkage reduction rate during reconditioning for three specimens treated at three moisture content levels.**

pression set. The validity of the above explanation is evidenced by the fact that depressions in the faces near the edges were first observed after 24 hours of drying. At that stage, natural shrinkage present in the core will be small, and the marked deformations in thickness are therefore very likely the result of compression set.

**Recovery Rate:** Recovery—time curves are shown in Figure 5 for flat-sawn, plain heartwood specimens reconditioned at three moisture content levels. Similar sets of curves were obtained for red heartwood specimens and for quarter-sawn material of plain heartwood. In all cases, the maximum rate of recovery of a given specimen was increased as the moisture content at the time of treatment was increased. This can be seen in Figure 5. The maximum rate of recovery is greatest for the specimen at high moisture content and least for the specimen at low moisture content. This can be explained if it is assumed that the degree of plasticizing that occurs upon heating is greatest in the material with the highest moisture content. From this it follows that the forces which act to restore the natural cell shape will act in the shortest period of time in the material of the highest moisture content. It is seen that recovery starts almost immediately and proceeds at a very rapid rate for the first 20 to 30 minutes. It is during this period that most of the recovery is obtained. According to calculations based on the work of MacLean (8), it should take approximately 30 minutes for the core of a 4/4 madrone board to reach the temperature of the reconditioning chamber. From this it appears that the initial recovery and perhaps the greatest percentage of the total recovery are greatly influenced by some phenomenon occurring in the outer layers of the material early in the treatment.

**Other Observations:** The average gains in moisture content during reconditioning were 5.2 and 6.4 percent for the red heartwood and the plain heartwood specimens, respectively. There were no significant differences in gains among specimens reconditioned at the three moisture content levels. The difference between the two heartwood types may be explained by the more severe collapse in the red-heartwood, which gave it greater density and, consequently, lower permeability.

After the specimens had been dried to 8 percent moisture content they were placed in a controlled-humidity room and brought to an equilibrium moisture content of 6.5 percent. At that point, the material was examined for the presence of drying stresses. It was found that the specimens were either stress-free or possessed a small amount of casehardening. In no case was reverse casehardening detected. This appears to be somwhat contrary to McMillen's work (7) in which he stated that there is a danger of severe reverse casehardening if material is steamed or exposed to excessively high relative humidity during conditioning treatments. This discrepancy is probably explained by the high temperature used in the reconditioning treatment since it is evidently responsible for the shrinkage recovery. The reverse casehardening condition which occurs during a conditioning treatment is the result of compression set which occurs as the shell of the board tries to expand but is resisted by the core. Since expansion occurs throughout the cross-section of material being reconditioned, the core no longer offers resistance, and therefore compression set does not occur.

It has been indicated (7) that exposure of material to the conditions of high humidity present during reconditioning may result in permanent openings of previously closed checks. This could not be fully corroborated by the present study since the material was dried without the occurrence of surface checking. However, there were a few checks at pin knots which opened noticeably during reconditioning. Since Pacific madrone can be dried with a negligible amount of surface checking, the openings of checks during reconditioning is not likely to be a serious problem. The opening of checks at knots cannot be considered a disadvantage since hardwood grading rules are based on cuttings, and call for the elimination of knots irrespective of their condition.

## Conclusions

Several variables influence the amount of shrinkage that occurs while madrone boards are being kiln dried. Those included in the present study were heartwood type, maximum kiln temperature, and growth-ring orientation. It is shown that these same variables have a significant influence on the final shrinkage in the material after it has been reconditioned and dried to 8 percent moisture content. This indicates that reconditioning is not always completely effective in eliminating the abnormal shrinkage occurring in the material. The factor that has the greatest influence on the final shrinkages is heartwood type. In general, the final shrinkage values for the red heartwood (described above) were approximately twice as great as those for the plain heartwood.

The final shrinkage is significantly increased if the material is exposed to high kiln temperatures for a prolonged period of time before reconditioning.

Tangential shrinkage is greatest in quarter-sawn material; i.e., tangential shrinkage is greater in thickness than in width. Volumetric and radial shrinkage are not significantly affected by growth-ring orientation within the board.

Final shrinkage can also be affected by the moisture content of the material at the time it is subjected to the reconditioning treatment. The effect can apparently be attributed to abnormal shrinkage resulting from severe final drying stresses following reconditioning. From this it would follow that the moisture effect is dependent on the kiln conditions used for final drying.

In general, it can be concluded that the reconditioning treatment is very effective in eliminating distortion and abnormal shrinkage in Pacific madrone lumber. It offers a means of producing dried material with a very small amount of drying degrade. In addition to the obvious advantages of reconditioning, it has been stated (3) that reconditioned boards are easier to machine and have greater dimensional stability than does similar untreated material. The only disadvantage found in the present study was that the treatment tended to open previously closed checks. This problem is not critical in madrone since it can be dried with very little surface checking.

## Recommendations

It is recommended that Pacific madrone lumber that is to be reconditioned be dried with a maximum kiln temperature no greater than 140° F. The reconditioning treatment should be performed when the material

reaches an average moisture content of 13 percent or less. The best results will be obtained if the material is reconditioned at 212° F. in a completely saturated atmosphere. However, good recovery can very likely be achieved at somewhat lower temperatures (3). A 2-hour treatment is necessary to obtain near optimum recovery. However, if the economic factor becomes important, this time can be reduced considerably without a serious loss in the benefits of the treatment (see Fig. 5). After reconditioning, the material can be dried to its desired moisture content level, with high kiln temperatures without danger of further degrade.

Since excellent recovery is obtained in Pacific madrone when it is reconditioned at 8 percent moisture content, it is probable that the species can be treated at the completion of the kiln run without the necessity of further drying. The moisture gained during reconditioning is held in the outer layers of the material and will probably evaporate to a large extent while the material is being cooled. If such a procedure can be followed, much of the extra handling necessary for reconditioning can be eliminated.

Since commercial kilns are not built to withstand the extreme conditions required for reconditioning, it is advisable that the treatment be performed in a separate steam chamber. The chamber can be of very simple construction since reconditioning takes place at atmospheric pressure. One steam chamber can serve a battery of many kilns because the time required for reconditioning is small compared with that for drying.

Although this study dealt only with Pacific madrone, it is reasonable to assume that the reconditioning treatment can be utilized with advantage for many other species. It is recommended that the possibility of utilizing the reconditioning treatment be investigated for all hardwood and softwood species that commonly possess a high degree of abnormal shrinkage and warp after drying.

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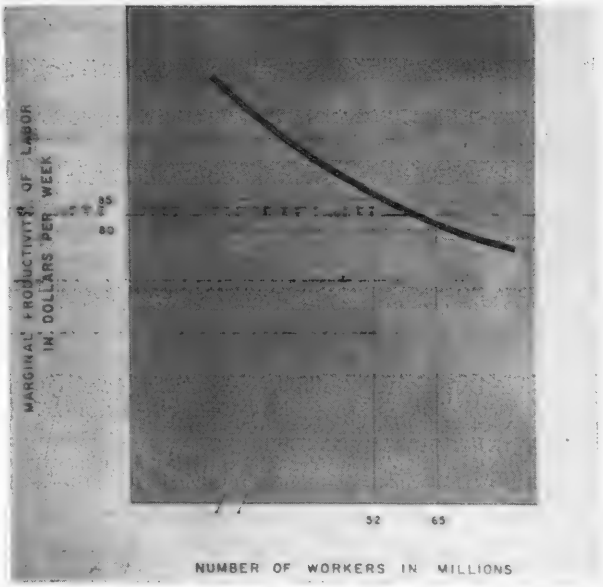


Fig. 1.—Relationship between marginal wage rates and employment.

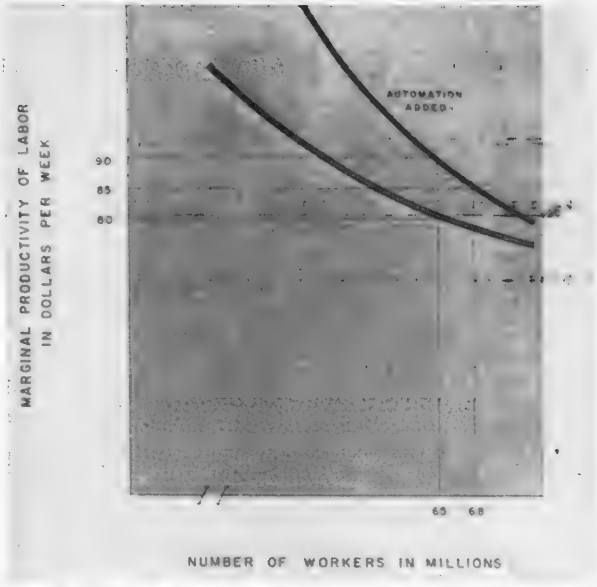


Fig. 2.—Effect of more efficient mechanization on price structure.

# Development

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**The development process is discussed as a key to a profitable future for the wood industries, with an emphasis on methods, mechanization, and management.**

OFTEN SOME MANUFACTURER comes to us for help and begins with a preamble such as this: "My manufacturing division is sick—it needs help. And I'm not looking for minor improvements. I want a really major step-up in productivity, and I want it fast!" I mentally paraphrase it this way: "Help wanted, no minor miracles need apply!" How do you perform miracles in manufacturing efficiency? Where you you attack the problem? If you are starting a developmental program, how do you justify the necessary outlay? How do you control the improvement process? How much will it cost and how can you spread the cost?

I don't know all the answers to these questions, but I have watched enough struggles in the development of machinery and processes to have detected some patterns—some underlying principles. Very little of this experience came from within the wood industries, but perhaps this "outside" point of view will be as valuable. I can, at least, give you some perspective on the development end of the nationwide "Research and Development" game.

## I. ATTACK METHODS FIRST

First of all, where do the opportunities for major improvements lie? If you are searching for the crack into which to drive a wedge, do you look at methods or machinery, at materials or men? Our answer has been to attack methods first, if you are really intent upon major miracles.

Look at it this way: If there were such a thing as an "average" plant in American industry, one might find in it a 100 men working on a dozen different materials at 80 machines, but probably all involved in a single process of manufacture. An improvement, no matter how brilliant, in one job or one machine or one material can have only a fractional impact on the total effectiveness of the factory. But a change in the process can affect every operation in the plant. The process is the common substratum. Whether you set out to bake a cake, build a transistor, or travel to New York, the first decision you make is to select a recipe, or a method, or a process. All other decisions as to equipment, materials, and men are subsidiary to the process decision.

Therefore, when major improvements are called for, I always look first

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to see what can be done to improve the basic process. It has been done in the wood industries, which are concerned with the conversion of trees into building materials. One process is to cut logs, notch the ends and lay up a log cabin. Another is to saw the logs into boards and nail up a box-like structure. Another is to peel the logs into veneers and glue the veneers into plywood. Still another is to grind the logs into chips and bond the chips into hardboard or chipboard. Finally, you can use the tree as a source of raw materials for a chemical process. Each of these basic processes implies widely differing equipment, materials and manual skills. Each introduces its own economics and all are quite different from one another. Granted, a change in process takes more time, more money, more skill and involves more risk than a change in one machine in your plant, but the payoff can be far greater.

### The "Freeze-in"

Not everyone can afford a major attack on his process; some must be content with a smaller program of progressive refinement of each machine, each operation and each skill. However, watch out for the "freeze-in" which may result from this strategy.

I have a client who is a large paper converter. Right in the middle of his process he has two operations that are still manual. They involve more pairs of hands, spoil more products and consume more time and space than all the rest of the operations in the process. We could have eliminated the difficulties by radically changing the process, but the cost (in time and money) was too high for their budget. Instead, the company sank about a third as much money into refinements in the two operations. Limited economies were effected, but the basic problems still remained. Now they can't afford to junk the recent capital investment, and they can't get rid of the squadrons of costly, careless, semi-skilled help. These have been frozen in by a short-sighted, short-range drive down a blind alley. Their developmental funds are all gone and the surface hasn't been scratched so far as the potential economies go.

## II. MOTIVES

There are a great many motives for entering into the development of processes or equipment. Broadly, these include reduction of labor costs, savings in materials, flexibility in the selection of raw materials, savings in floor space, decreased power consumption and other factors leading to reduced cost per unit of output. Then, there is the desire to improve product quality and uniformity. But there are other, more subtle, although still very convincing reasons for entering a development project. I want to touch upon these because, in general, they defy the usual cost accountants' approach to justification and are therefore too frequently ignored. There are such considerations as the availability of by-products, or supplementary product lines; the reduction of the time necessary to train workers; the freedom from governmental oversight; the reduction of delivery time to customers due to faster processes and automatic warehousing; the reduction of in-process inventory; worker safety and morale; flexibility of product design and other similar factors.

There are some processes which just could not be carried out without advanced mechanization. Mechanized computation is an example of a function which simply could not be performed manually (or should I say mentally) at an economically justifiable rate. Strip mining of coal is another good example of a process which couldn't be undertaken without the huge multimillion dollar power shovel used to remove the overburden.

### Broader Effects

We ought to consider the broader effects that additions to the capital structure will have upon wages, unemployment and productivity. I am going to explore this point in depth for two reasons: first, it cannot be ignored as a motive in justifying development programs; second, it is a widely misunderstood relationship, and anything we can do to set it straight in the public mind is worthwhile.

Let's illustrate the relationship between marginal wage rates and employment by referring to Figure 1. Senator Paul Douglas' studies have shown that the elasticity of the demand for labor is close to minus four. An increase in marginal wages from $80 to $85, or 6 percent would cause more than a 20 percent decline in employment, all other things being equal.

The sequence of the logic is: If wages must be increased without a corresponding increase in productivity, then the labor cost per unit of product must rise. Assuming that the product was initially priced as low as possible to compete with other products, the manufacturer must then either operate at an unprofitable level, go out of business or raise prices. An increase in prices implies a decrease in production, in accordance with the well-known laws of supply and demand; and a smaller production means a smaller employment.

To say this another way, if wage rates go up and worker productivity (or machine productivity) does not go up correspondingly, then marginal equipment and workers go out of use and employment goes down. Conversely, a decrease in marginal wage rates means an increase in employment.

But if the manufacturer can offset decreased worker productivity with increased machine productivity, then the price structure can be held and there will be no decreased employment. Greater machine productivity is achieved first, by the development of better and more efficient machines and processes; and second, by the investment of capital in the purchase of these new machines. Professor Yale Brozen of the University of Chicago has shown that with the availability of increasing mechanization, the marginal productivity curve rises on the diagram. The reasoning is that when more efficient production machines become available employers can afford to hire workers whose wage rates were too high to permit using them on the older, less-efficient equipment without suffering a loss.

As shown by Brozen (Figure 1), while formerly a labor force of 65 million was only possible with $80 wages, the advent of more efficient machinery has allowed the wage rate to rise to $90. Actually the increased wage rates draw more people into the labor force, and the situation might stabilize at $85 with 68 million employed. (Please note that these figures are illustrations, not predictions).

A rise in machine productivity thus minimizes unemployment; it does not cause it. In other words, if machine productivity had not increased over the past decade, unemployment would be greater than it now is.

### Higher Wages vs. Mechanization

In the past decade two factors have been active: the employment-destroying effect of the tremendous increase in real wages; and the employment creating effect of mechanization. The former has been the dominant factor and unemployment has been creeping up. This very thing—the dominance of the upward creeping of real wages is a powerful incentive to mechanization, and mechanization—as I hope I have shown—is beneficial both to the manufacturer and to labor.

More and more labor unions are sponsoring research in their particular craft or trade as a hedge against potential obsolescence. This raises the question of the effect which develop

ment and the consequent greater capitalization may have on wages. It can be shown that, for the addition of every $1000 investment in our industrial economy national income will be $350 a year greater thereafter. Twenty dollars of this will go to local real estate taxes, $50 to the Federal Government in corporate income taxes; $60 will go back to the investor as interest or dividends and $220 will go to labor as increased wages. So you see that many unions are composed of foresighted men.

## III. ECONOMICS

If justification is to be based upon a numerical calculation, all the pertinent factors listed above must be gathered into one measure. Every single factor should be taken into account when one starts to estimate the economics of developmental programs. We figure out the total cost of doing business with and without the proposed development and compare the two. It's relatively easy to appraise the present cost, in money, sweat, and tears; but the real trick is to think out and evaluate all the changed conditions which will come to pass under the proposed system. Don't forget that these considerations involve every person, every function, and every facet of an organization. I mean this to be a sweeping statement, for to leave out any remote factor diminishes by just that much the validity of the conclusions.

There are, of course, cases in which the development can be shown to have so limited an effect that a full-dress evaluation is not warranted. A common approximation is to measure the labor savings against developmental and equipment costs, using as an index the number of years savings required to pay back the capital investment. This has its hazards and its limitations, but also its uses.

### Method

It works this way: You add up estimated outlays on development, prototype machines, debugging, and duplicate machines. You can subtract the salvage value of displaced machines if it is known. This represents the outlay. Next you estimate the savings in labor and materials per year. Dividing the total outlay by the annual savings gives a number which is the criterion, expressed as the years required to pay back the outlay. When this number is a fraction, you can afford to get excited; if it is over 10, the project is rarely interesting.

### Low Payouts

Each industry has a range of numbers in which the payout index must fall to be justified, and each company in turn has limits depending on its own internal conditions. Industries in which style, fashion, and timing are important like to see payback periods of 9 to 18 months; if you made hula hoops, you wouldn't consider any development program which ran over two months, or the market would be gone before you got your investment out. Soft goods, clothing, amusements, etc., fall in this quick pay-back class.

Particularly low payouts are important for the manufacturer with a small capital investment relative to the value of product handled. He wants to be able to dart in and out of the market to take advantage of every opportunity, and can afford periods of complete inactivity without heavy equipment depreciation charges. An example might be the purchase of machines to tie ribbon bows for candy boxes.

### High Payouts

More stable items, or industries with considerable capital investment find periods of 1 to 3 years attractive. Sometimes we find a business which is glad to get opportunities for payouts of 5 to 9 years, but these are in industries where the product is in stable demand, and stable supply, where most of the quick, easy improvements have been made already, and where competition is pressing hard. With such long payout periods, the product must have a very sure market, or the machinery must be almost universally adaptable to changing products. Numerically controlled machine tools and printing presses would come in this category.

Let me point out that there are several hazards in the payout period criteria. Obviously it ignores the time factor in the return of capital, which becomes significant in periods over 2 years. Also it ignores the effect of taxes and the cost of capital, the intangibles such as quality and uniformity of product, saleability of improved product, safety and morale, cost of in-process inventory, etc. And it tends to over-emphasize the significance of the labor cost as an element of product cost.

Variations of this formula are able to take into account depreciation of the machine (which assumes you know in advance how long it will last) using a variety of depreciation curves and salvage value.

### Discounted Cash Flow Method

Far and away the most sensitive and inclusive method of evaluating developmental projects is the discounted cash flow method. While the procedure is too complicated to rehearse here in detail, this much can be said. An estimate is made of the net cash flow involved in the project for every year involved. It can include past years as well as future years, so that the analysis may be made at any time in the life of a project. These net cash flows include all known or estimatable costs, including research, development, debugging, duplicate machines, rent, power, materials, labor, training, supervision, maintenance, and repair. These factors may vary from year to year in a realistic manner, and may be made as all inclusive as your ingenuity or knowledge permits.

Each year's net cash flow is then discounted to a present value, accounting for the fact that the promise of a dollar income 10 years from now is not worth a dollar today. The rate of return on investment is determined by mathematical methods for the project. This rate of return may be, for example, 25 percent. It can be compared with any other project you have in hand, thus ranking them in a relative order of attractiveness. Also, you can compare a new machine development directly with other projects such as a new boiler for the power plant, paving the parking lot, or a national advertising campaign. In general, the wise manufacturer spends his money where the greatest rate of return is available, working down the ladder of opportunity until he runs out of money or drops below his cost of capital. Obviously you don't put money in a developmental project in which the expected return on investment is less than your cost of capital. We have applied this discounted cash flow method successfully many times as a criterion for economically evaluating R & D work, and find it excellent.

## IV. MANAGEMENT AND CONTROL

Now we come to the management and control of the development. The developmental process is a continuum —a continuous stream of evolution from end to end. It is true that some points in the process are easily distinguished from other points in the process by one means or another, but the transition lines in between are fuzzy and elusive.

I distinguish between Research and Development on the basis of objectives; in applied research we are looking for facts—dependable knowledge of how or why things are what they are or work the way they do. In development we are looking for merchantable products—we use the knowl-

edge to design something which can be made and sold profitably.

### Pilot Plant

I distinguish Development from Pilot Plant operation—a point on the continuum—on the basis of number of samples. The development man is content to get one design and build one working model or unit. He proves that he has applied his knowledge successfully. The pilot plant man starts the repetitive process of manufacture—he strives to produce many units, and surmounts such problems as variables in raw materials, operating conditions, and careless operation.

I distinguish Pilot Plant from full Production on the basis of reliability. In the pilot plant we put up with down-time for alterations and improvements, operator training, and the like. In production we expect the process or the machine to run reliably day after day.

These criteria are pretty broad, but the facts of the case don't lend themselves to sharp definitions, and the course of a project rarely runs smoothly from Research to Development to Pilot Plant to Production. It back-tracks and stumbles and divides and dawdles.

### Managing the Project

The point here is to remember that these divisions *are* arbitrary and ill-defined, and that the course of a project, like true love, is seldom smooth. You need different kinds of men, different kinds of management, and different criteria of controls in the various stages. Managing the show is a little like running an amateur theatrical group; it takes infinite tact and dogged persistence. But while organizations and controls may differ, the project is continuous. Usually you have one organization start the project through the research stages, and quite a different one to finish it up at the pilot plant end. Some companies are big enough to have an intermediate organization on a co-equal status to handle the development. But this means three transfers of knowledge and responsibility, and every extra transition is a hazard.

In old arts, such as the design of machine tools for specific industries, the research functions and the development functions, are grouped under one head, and pilot lot testing is a function of production. In newer arts such as the production of transistors, research comes under one head and development and pilot plant operations are grouped together and may even be a part of the production division. This is because much of the developmental work must be done on a real product flow, and the pilot line becomes the main production line as soon as it becomes sufficiently reliable.

The more automation creeps into our factories, the more the product design engineer tends to dominate the production engineers, and the more the laboratory dictates factory procedures and practice. If we ever get to the point where the whole factory is one great machine, the lines between development, pilot plant, and factory will disappear forever.

## V. COST CONTROLS

How much will developmental projects cost? The man with the answer to this question has his fortune made. As a man with background in automatic machinery, I find certain rules of thumb handy for making estimates, but any estimate must be tempered with two parts of judgment for every one part of estimating systems. Also, remember that the development objective frequently evolves or "rolls" as it is pursued. Every time it changes you should revise your cost estimate. A sad but direct analogy is the common experience of home builders; seemingly trivial changes are the excuse for substantial "extras" added to the contract price. So, when you look back at the end of the job to compare the actual costs with the original estimates, stop to think whether the final result was what you originally set out to do. Nine times out of ten it will be different. If it isn't you haven't exercised adequate imaginative vigor!

### Actual Costs vs. Estimates

I was recently shown an automatic production machine during the course of a casual visit to a plant. The proud superintendent asked me how much I thought it cost to produce that one working unit from scratch. My guess was $35,000; $5,500 was his boast! I could count $2,000 worth of purchased components—parts feeders, dial table, geared motors, photo cells, drill press heads and columns, and the like.

"How did you achieve that cost figure?"

"Designed it myself one evening at home; the chief engineer bought the parts for us. (Both these men were carried on overhead accounts.) I told the Tool and Die shop boss how to assemble it, and the plant electrician wired it up. Debugged it right on the production line; used the maintenance crew and the shop subforeman."

What this comes down to is that every bit of the job was hidden in overhead accounts except purchased parts, materials, and actual machinist's time making special parts. The sad part of this happy delusion is that the man now measures all machinery on the basis of this puny and distorted yardstick.

### Realistic Costs

On the other hand, the big corporations who do enough development work and keep good enough accounts really know what it costs to create, build, and install a finished automatic machine. Taking into account all the costs properly allocable to development, I expect the study, design, layout, and detail portions of the work to total 25 to 30 man hours per part. Two-thirds of this will be time spent by a senior man, and the remaining third will be spent by a junior man or detailer.

The basis of this estimate is a "part." This may be any part of the machine from main frame to name plate, just so long as it has to have a detailed drawing made for it. Purchased parts such as ball bearings, nuts and bolts, motors, etc., don't count; assembly drawings don't count. If there are 50 identical parts used per machine, they still count as one because one drawing serves for all.

Further, I anticipate the same number of man hours in the machine shop to build and assemble one set of parts. This carriers the prototype machine to a point where it is ready for test.

On some such basis, tempered widely by judgment, we arrive at a dollar budget. As work progresses, I expect the study plan to be pretty well over by the time 20 percent of the funds have been expended. Design work should be done when 40 percent of the funds are gone. The machine should be detailed and built when 80 percent of the funds are gone. The remaining funds cover testing and modification.

### Debugging

"Debugging" is an inelegant term for a nasty but essential task. My father was a combustion engineer, designing automatic coal stokers, among other things. He taught me long ago that if there are a 100 bolts on a stoker, 10 of them will loosen up within a week. You go out and set them up tight with a big wrench, but next week one of them will be loose again. Debugging is that seemingly endless phase when you fix first one thing and then another until the machine not only performs as you hoped but keeps on performing.

It may be fully as expensive as all that has gone before; or a really good

lesigner may turn out a job which an be debugged for 20 percent of the lesign-and-build cost. There is really o good rule for this, except that it s disappointingly expensive and frus-ratingly time consuming. It's always here on every project, but managers never seem to remember to allow or it.

### Consultants

Some of you may call upon consultants to help with development projects. Usually an outside firm is called or one of three reasons, all valid. First, you may have your own engineering division but find it overloaded from time to time, and want to farm out the peak loads. Everyone has peak loads, and it is far more economical to farm out the peak loads than to support a force year in and year out capable of handling the peak load and have it partly idle most of time. You'll find a good consultant very close to the same cost as your own development department if you keep good enough books to really know your own costs.

Second, you may have an unusual problem completely foreign to your own developmental skills. Again, you can get a consultant for far less than the cost of adding a specialist, equipping his laboratory, and then letting him go.

Third, you may be one of the many American firms with no research and development group at all. If you decide to embark on a project under these circumstances, you will undoubtedly contract for the work, at least in the beginning. If you are in this position, pull back and take a good long look at what you are about to do. You should comprehend fully all the implications for your entire company of the proposed activity before you start into the development game.

### Bidding

A word about the way the consultant may bid on the project. You may require a fixed price bid with a guarantee of performance and delivery date. If you do, and anyone bids, you can conclude: a) that there is so little experimental work about it that you shouldn't class it as developmental; or b) that the bidder is desperate for work; or c) that he didn't understand the problem. If he bid what he really thought it would cost, the chances are he will be in financial difficulty before he is through; if he was smart and bid high enough to cover any possible contingency, the chances are you will pay more than you need to.

My suggestion is to pick a consultant in whom you have faith, and then let out the work a phase at a time. The risk of estimating the first phase is not great; each following phase can always be better estimated at the close of the preceding. With this system, you can stop after any phase and think it over.

Above all, don't solicit outside bids to use as a club over the heads of your own development department, or to make them look good before Management. This is hitting below the belt.

## VI. DEVELOPMENT

The American economic system of free enterprise is about as competitive as any environment short of the primitive jungle. You compete with your next door neighbor for labor; you compete with human nature to get efficiency; you compete with others in the same industry for sales; your whole industry competes with other whole industries who make alternate products to serve the same purposes as do your own; and all of us compete for the consumers' dollar. The cream goes to the product, or to the industry, or to the corporation, who gives just a little bit more than any one else for a dollar's worth of sales. And so we strain to perfect our products. This is called development, and it moves always on an upward spiral. If you start it, your neighbor must match you or fall behind. It is a little like starting down a roller-coaster ride. Once committed, there is no turning back, and only acceleration ahead.

Make no mistake, the American industrial economy is as firmly committed to the research roller coaster as our social economy is committed to the automobile. And it is almost as expensive. How can you spread the cost of research and development, or at least minimize it?

### The Production Unit

The least expensive ride you can buy is the development of just one machine. When the pilot model is debugged and working, it becomes the production unit. You pay for development and the production machine all in one, and it is presumed that you do not start unless the project will pay its way.

The next level occurs when the pilot model is followed by a small number —say 10,—duplicate machines for your production lines. Here you spread the development cost over the 10 units, and you achieve some economy by building a lot of 10 machines instead of one. Generally, the prorated development cost is well below the cost of the individual machine units, and the bigger the lot of machines the more insignificant becomes the developmental cost.

### Protecting the Development

The price tag may still look high, but do not forget that you alone in the industry have the advantage that the machine or process gives. If the development was worth its salt, you can protect it either by patents or by secrecy, and retain all the economies. Or you can license or sell it to the rest of the industry after you have enjoyed a 2 or 3 year lead on your competitors. This is a common practice in the automotive field. Actually, you might as well share it after a little time, because an alert competitor will match it with another development of his own. And in a rapidly evolving technology, a development may be obsolete in 5 years anyway.

If the price tag is still too high, the door may yet remain open through a trade association development. We have many instances in which an industry has approached us through its association or a small confederation of members to share jointly in a development too big for any one alone.

Of course you lose the individual edge on your direct competitors, but this may be secondary to the value received. It must be admitted that research or development by or for a trade association is prickly with management problems. Ownership of the development, sharing of costs, patent management, licensing to others, and many other problems are difficult but not insurmountable.

### Development for the Future

An industry such as yours might quite properly enter into a long-range, industry-wide development program as a key to a profitable future. The record shows that the industries with the greatest investment in mechanization have made the greatest gains in over-all employment and in total volume of business. The steel, automobile, telephone and chemical industries are examples.

Finally, you can take advantage of the tremendous research programs supported by Federal and state funds. Half the research in the country today is supported by Uncle Sam, and not all of it is going into intercontinental ballistic missiles and space stations. The U. S. Forest Products Laboratory at Madison, the various regional laboratories, and the Bureau of Standards are all turning out splendid work that is available to all. Indeed, we all have a part in paying for it, so we should take advantage of it.

# Chemical Composition of Tannins and Polyphenols

## FROM CONIFER WOOD AND BARK[1]

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Contribution No. 57

CURRENTLY, there is considerable interest in conifer polyphenols from both applied and fundamental standpoints. Monomeric polyphenols, such as catechin, dihydroquercetin, and quercetin, can be obtained in commercial yields from the bark of white fir and Douglas-fir, and are potentially useful as antioxidants, pharmaceuticals, and so forth. The polymeric compounds, such as tannins, phlobaphenes, and "phenolic acids", are available in large volume by extraction of bark and wood residues of the lumber and pulp industries. They have proven utility in leather tanning, oil-well drilling, preparation of adhesives, ore flotation, and other applications. In addition, there is interest in the composition of heartwood polyphenols because some of them are responsible for the inhibition of sulfite pulping of certain coniferous species. They may be related to heartwood formation and color of wood. The possibility has been suggested that these compounds may be good taxonomic indicators, that is that they may be used to distinguish closely related species or genera chemically.

Very little was known about conifer wood or bark polyphenols until 20 years ago. At that time, Erdtman's classical studies on pine heartwood constituents and their relationship to sulfite pulping were initiated. Since that time, work on coniferous heartwood constituents (mainly lignans rather than polyphenols) has been extended to additional genera by Erdtman, Freudenberg, Gardner, Zavarin, and others. The nature of some of the monomeric polyphenols present in the bark of several coniferous genera has been reported by Kurth and coworkers. The chemical structure of the polymeric polyphenols, such as, tannins, phlobaphenes, and "phenolic acids", which are actually of considerably greater economic interest than the monomeric compounds, has remained obscure, however,

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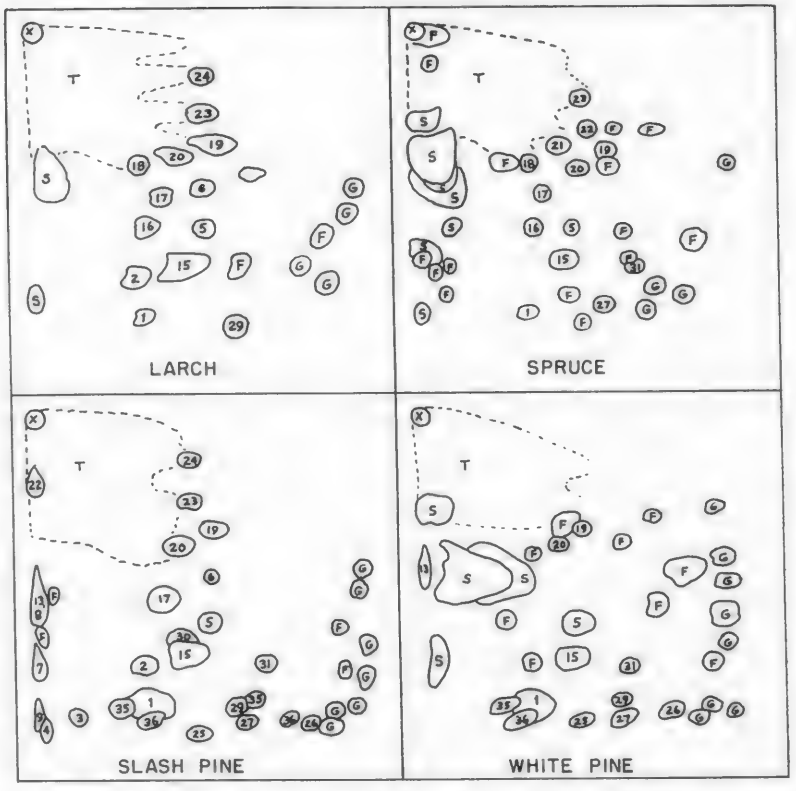
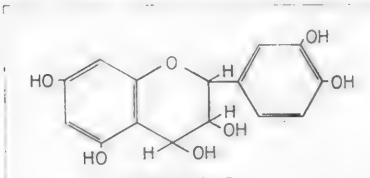



Fig. 1.—Two-dimensional chromatograms of the methanol extracts of A) Western larch bark; B) Sitka spruce bark; C) Slash pine bark; and D) Western white pine bark. Identified compounds are numbered as follows: 1. Dihydroquercetin; 2. Dihydromyricetin; 3. Dihydrokaempferol; 4. Pinobanksin; 5. Dihydroquercetin glucoside; 6. Dihydromyricetin; 7. Quercetin glucoside; 14. Myricetin glucoside; 15. Catechin; 16. Epicatechin; 17. Gallocatechin; 18. Epigallocatechin; 19–22. Leucocyanidins A–D; 23–24. Leucodelphinidins; 25. Coniferylaldehyde; 26. Vanillin; 27. Vanillic acid; 29. Protocatechuic acid; 30. Gallic acid; 31. Phloroglucinol; 35. Caffeic acid. 36. Ferulic acid; T. Polymeric tannis; S. Substituted stilbenes; F. Unidentified substances fluorescent under ultraviolet light; G. Unidentified guaiacyl derivatives, X. indicates origin. Chromatograms were developed from top to bottom, with organic phase of butanol-acetic acid-water (4:1:5) and from left to right with 2 percent acetic acid.

**Flavonoids and related polyphenols were characterized by paper chromatography. Polymeric tannins were shown to be primarily derived from leucocyanidins and from catechin.**

Studies recently conducted in this laboratory have shown that the aqueous tannin extracts of pine (1)[2] and fir (*Abies* sp.) (2) yield identifiable anthocyanidins when heated with mineral acid and alcohol. The components of these tannin extracts were separated chromatographically, and it was found that two types of materials were responsible for this reaction. One of these consisted of a series of stereoisomers of leucocyanidin (structure I) (3). These compounds are crystalline



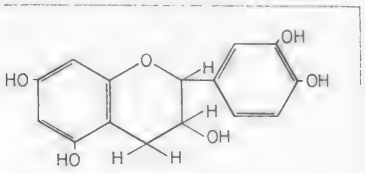

FORMULA I

[1] A contributed paper, received Nov. 23, 1959, and approved for publication March 4, 1960.

[2] Numbers in parentheses refer to the Literature Cited at the end of this paper.

after separation and purification, and they move as discrete spots during two-dimensional paper chromatography.

The other material that gave cyanidin upon acid treatment was amorphous and was relatively immobile during chromatography. It comprised the bulk of the phenolic portion of the aqueous extract and was fixed on hide powder, which indicates it was a tannin. This material was obviously polymeric, and from elemental analyses, degradation, and biogenetic considerations, it was shown that this polymer (or mixture of polymers) was derived from leucocyanidin and catechin (structure II). The mode of linkage of the monomers has not yet been



FORMULA II

definitely ascertained, but spectral data strongly suggested ether linkages. In view of this discovery, it appeared to be of interest to investigate additional coniferous genera to determine whether other coniferous tannins have similar structure. Other objectives of this investigation were to determine whether monomeric polyphenolic constituents from bark could be useful for taxonomic purposes, and whether wood polyphenols were related to heartwood formation.

## Experimental

**Identification of Monomeric Polyphenols:** Wood, bark, and needle samples were obtained from various localities as shown in Table I. These trees, along with those in the previous studies (1, 2), represent all of the coniferous genera (though not necessarily the exact species) commonly used for pulpwood in North America. The wood and bark were chipped, further reduced in a Wiley mill to pass a 20-mesh sieve, and dried as soon as possible after trees had been cut.

In order to characterize the monomeric polyphenols qualitatively and to determine their distribution in various parts of the tree, methanol extracts were submitted to two-dimensional paper chromatography. The extracts were prepared by suspending a 100 gram sample of sapwood, heartwood, inner bark, or outer bark in one liter of methanol. After 24 hours, the extract was filtered off and then two additional 24-hour methanolic extractions were performed. The extracts were combined, evaporated to a small

Table 1.—COLLECTION DATA ON WOOD AND BARK SAMPLES

| Common name | Scientific name | Age of tree (Years) | Geographic location |
|---|---|---|---|
| Atlas cedar | *Cedrus atlantica* var. *glauca* | 40 | Shelton, Washington |
| Baldcypress | *Taxodium distichum* (Linn) Rich. | 60–200 | Southeastern Georgia |
| Douglas-fir | *Pseudotsuga menziesii* (Mirb.) Franco | 40–200 | Mason County, Washington |
| Engelmann spruce | *Picea engelmanni* Parry | 80 | Southeastern Washington |
| Redwood | *Sequoia sempervirens* (Lamb.) End. | 300–500 | Northwestern California |
| Sitka spruce | *Picea sitchensis* (Bong.) Corr | 8,150–450 | Northwestern Washington |
| Slash pine | *Pinus elliottii* var. *elliottii* | 30–120 | Northeastern Florida |
| Western hemlock | *Tsuga heterophylla* (Raf.) Sarg. | 50–150 | Mason County, Washington |
| Western larch | *Larix occidentalis* Nutt. | 12 | Seattle, Washington |
| | | 75–125 | Southeastern Washington |
| Western red cedar | *Thuja plicata* Donn | 125 | Grays Harbor County, Washington |
| Western white pine | *Pinus monticola* Douglas | 25–125 | Grays Harbor County, Washington |
| Yew | *Taxus brevifolia* Nutt. | 80 | Mason County, Washington |

volume *under vacuum,* and then spotted on 18 by 22 inch sheets of Whatman No. 1, 52, and 54 chromatographic paper. The sheets were irrigated by the descending method with the organic phases of Lindstedt solvent (4) (benzene-ligroin-methanol-water, 50:50:1:50), tolueneacetic acid-water (4:1:5), or butanol-acetic acid-water (4:1:5) in a Reco A300 Chromatocab.

Successful results could only be obtained in the first two solvent systems if the tank was thoroughly saturated with the aqueous phase. This was accomplished by irrigating sheets in adjacent troughs with the aqueous solvent phase. Best results with the butanol system were obtained, however, by avoiding a prior water-saturated atmosphere. Solvents were removed and the tank atmosphere was equilibrated with that of the room prior to each determination. Sheets were then inserted and the aqueous and organic phases added in the usual manner. When this technique was used, the Rf values of some of the compounds were lower than those reported in the literature, but better resolution of high Rf compounds was achieved. After irrigation, the sheets were removed from the tank, thoroughly air-dried, turned 90°, and irrigated in the second direction with 2 percent acetic acid.

The sheets were dried and examined under a short-wave ultraviolet lamp before and after fuming with ammonia vapor. They were then sprayed with various chromophoric reagents to characterize the phenolic compounds. Ferric chloride-potassium ferricyanide (5) was found to be a useful reagent for detecting all phenolic constituents present. Cinnamaldehyde (2 percent) and hydrochloric acid (5 percent) in alcohol gave colors only with unconjugated phloroglucinol or resorcinol derivatives, pyrogallol compounds, and a few aromatic amino acids. Thus, yellow-brown spots were obtained with catechins and gallocatechins, gallic acid, phloroglucinol, and pyrogallol, and reddish-brown spots with leucocyanidins and leucodelphinidins. Para toluene sulfonic acid (5 percent) in alcohol (6) was also found to be of utility in distinguishing leucocyanidins from the corresponding catechins, but somewhat less specific in that it also produced colors with flavanones, flavones, and so forth.

Bis-diazotized dianisidine (7) gave red to purple-brown colors with all flavonoids having a phloroglucinol nucleus, and with other phenolic compounds containing a catechol or pyrogallol group. This reagent was not suitable for the detection of guaiacyl compounds. Diazotized sulfanilic acid (8) spray reagent proved to be the most generally useful reagent, since it gave different colors with a wide variety of phenolic compounds. This reagent was applied in two parts, a butanol solution of diazotized sulfanilic acid, followed in four minutes by 10 percent sodium carbonate solution. Prior to application of the latter solution, colors were produced only with catechins, leucocyanidins, and phloroglucinol. After spraying with sodium carbonate solution, flavanones and para-hydroxy derivatives (para hydroxy benzoic acid and para hydroxy phenyl alkyl derivatives) also gave a yellow color. Guaiacyl derivatives without an alpha hydroxyl or carbonyl group gave a pink color. Vanillic acid, guaicol, and alpha hydroxyl guaiacyl derivatives gave an orange color, while ferulic acid gave an intense magenta coloration. Ferric chloride solution (2 percent in water) was used to distinguish between catechol (green coloration) and pyrogallol (blue-black coloration) derivatives. Phloroglucinol-hydrochloric acid (5 percent) in alcohol gave a magenta color with coniferylaldehyde and a peach color with vanillin. It was used to detect these two compounds specifically.

The identity of polyphenols that occurred in the bark, sapwood, and heartwood of various coniferous species is shown in Tables 2 and 3. In those instances where compounds were present in very small amounts, it was necessary to fractionate the extract further. This was done by liquid-liquid extraction of the water-soluble fraction with benzene, ethyl ether, or methyl ethyl ketone. The fractions were then chromatographed two-dimensionally.

Table 3—DISTRIBUTION OF PHENOLIC CONSTITUENTS IN CONIFEROUS WOOD

| Species of wood | Constituents: Catechin | Epicatechin | Leucocyanidins | Polymeric leucocyanidins |
|---|---|---|---|---|
| Douglas-fir sapwood | + | + | + | T |
| Douglas-fir heartwood | ---- | ---- | ---- | + |
| Sitka spruce sapwood | T | ---- | T | ---- |
| Sitka spruce heartwood | ---- | ---- | ---- | T |
| Slash pine sapwood | T | ---- | T | ---- |
| Slash pine heartwood | ---- | ---- | ---- | T |
| Western hemlock sapwood | + | + | + | T |
| Western hemlock heartwood | T | ---- | ---- | + |

Symbols: + = compound present; T = trace of compound present.

Several species contained stilbenes, which are easily discernible on chromatograms because of their intense fluorescence under ultraviolet light. They were non-mobile in the aqueous solvent systems. The structures of these compounds have not yet been determined. Since these compounds appear to be characteristic for a given species, several chromatograms are presented in Fig. 1 for reference.

**Isolation of Polymeric Polyphenols:** Polymeric polyphenols (tannins) were isolated from bark by a procedure designed to separate the tannins from sugars, polymeric carbohydrates, and monomeric polyphenols that accompany the tannins in a typical aqueous extract. Fresh bark, ground to pass a 10-mesh sieve, was immersed in boiling water (1 part bark to 10 parts water) for 1 hour. The bark was filtered off and submitted to 3 additional 1-hour extractions. The extracts were then combined, cooled, filtered, and evaporated to about 40 percent solids in a glass, countercurrent evaporator under vacuum at 35° C. The extract was then poured into a 20-fold volume of methanol to precipitate the polymeric carbohydrates (starch, pectin, and so forth). After the precipitated carbohydrate was washed with methanol, acetone, and ether, it was dried in a vacuum oven and retained for analyses. The filtrates were combined and evaporated to about 40 percent solids. This solution was poured into a 20-fold volume of 15 percent sodium chloride solution. The precipitated tannins were filtered off, washed with fresh salt solution, and air-dried. They were then taken up in absolute methanol, filtered to remove salt, precipitated into ether, dried, redissolved in methanol, reprecipitated into ether, washed with benzene, and dried in a vacuum oven at 55° C. Residual salt content (by analysis) was approximately 5 percent. Chromatographic analyses for sugars by a modified method of McCready and McComb (9) showed the absence of free sugars. Two-dimensional chromatograms showed that the tannin fractions of bark, when prepared in this way, were virtually free of monomeric polyphenols. One exception to this was Sitka spruce bark tannin. In this instance, the solubility properties of several compounds, presumably stilbene glucosides, were so similar to that of the polymeric tannin fraction that they could not be separated.

Infrared spectra of polymeric tannin and carbohydrates fractions, some of which are shown in Figs. 2 and 3, were determined by the potassium bromide wafer method with a Perkin-Elmer Model 21 spectrometer. Ultraviolet spectra of the tannin fractions were determined in ethanol with a Cary Model 11 recording spectrophotometer (see Figs. 4 and 5).

Ethanol solutions of the tannin fraction from each species were tested for the presence of specific phenolic nuclei as follows: Treatment with cinnamaldehyde and hydrochloric acid (5 percent) gave an intense orange-red coloration in each case. This is indicative of the presence of unconjugated phloroglucinol nuclei. Treatment with 2 percent ferric chloride solutions produced in every case an intense green to greenish-blue coloration, which is indicative of free catechol groups. To detect the presence of flavan-3, 4-diol nuclei in a polymeric tannin fraction, tannins were dissolved in n-propanol and hydrolyzed with hydrochloric acid by the procedure of Hillis (10). The visible absorption spectrum of the hydrolyzate was determined, and the presence of cyanidin and delphinidin was confirmed by paper chromatography by the procedure of Bate-Smith (11). Cyanidin and delphinidin, required as standards, were prepared by similar acidic hydrolysis of leucocyanidin and leucodelphinidin obtained by sodium borohydride reduction of dihydroquercetin and dihydromyricetin, respectively (1, 12).

Table 2.—PHENOLIC CONSTITUENTS PRESENT IN VARIOUS SPECIES OF CONIFER BARK

| Compound | Rf in butanol-acetic acid-water (4:1:5) | Rf in 2% acetic acid | Atlas cedar | Baldcypress | Douglas-fir | Engelmann spruce | Pacific yew | Redwood | Sitka spruce | Slash pine | Western hemlock | Western larch | Western red cedar | Western white pine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dihydromyricetin | 0.70 | 0.30 | T | . | . | . | | | | + | | + | | |
| Dihydromyricetin glucoside | .48 | .50 | .. | . | . | . | | | | + | . | + | .. | |
| Dihydroquercetin | .81 | .36 | + | .. | + | + | | | + | + | | + | + | + |
| Dihydroquercetin glucoside | .56 | .55 | + | .. | + | + | | | + | + | | + | + | + |
| Dihydrokaempherol | .85 | .15 | .. | .. | .. | .. | | | | + | .. | . | .. | |
| Pinobanksin | .90 | .05 | .. | .. | . | . | | | | + | .. | .. | .. | |
| Myricetin | .57 | .00 | .. | .. | | | T | . | | + | . | .. | .. | . |
| Quercetin | .74 | .00 | . | T | + | | + | | | + | + | . | .. | . |
| Epigallocatechin | .40 | .33 | .. | T | | | T | T | | | T | T | .. | |
| Gallocatechin | .48 | .39 | T | + | .. | | T | + | | + | T | T | .. | . |
| Epicatechin | .56 | .37 | T | + | + | | + | . | | | + | + | + | . |
| Catechin | .68 | .46 | + | + | + | + | + | + | + | + | + | + | + | + |
| Leucocyanidin A | .48 | .57 | + | + | + | + | + | + | + | + | + | + | .. | + |
| " B | .45 | .50 | + | + | + | + | + | + | + | + | + | + | + | + |
| " C | .40 | .45 | + | + | + | | + | T | | | + | . | + | |
| " D | .42 | .51 | + | + | + | | + | T | | . | + | . | . | |
| Leucodelphinidin(s) | .16–.30 | .40–.53 | + | + | .. | | + | + | | + | . | T | .. | . |
| Gallic acid | .70 | .50 | .. | + | .. | .. | | + | | T | . | .. | .. | .. |
| Protocatechuic acid | .88 | .58 | + | + | + | .. | + | + | + | + | + | + | + | + |
| Phloroglucinol | .75 | .65 | + | + | T | + | T | + | + | + | + | + | + | + |
| Caffeic acid (*trans*) | .77 | .25 | .. | .. | .. | .. | | | | + | . | . | + | + |
| Ferulic acid (*trans*) | .84 | .33 | .. | + | T | + | | | | + | | | + | + |
| Coniferylaldehyde | .90 | .45 | + | + | + | + | | + | | + | + | + | + | + |
| Vanillin | .92 | .68 | + | + | + | + | | + | + | + | + | + | + | + |
| Unknown stilbenes* | | | 2 | | | 11 | | | 16 | .. | .. | 2 | .. | ? |

Symbols: + = compound present, T = trace of compound present.
* numbers indicate number of different stilbenes present.

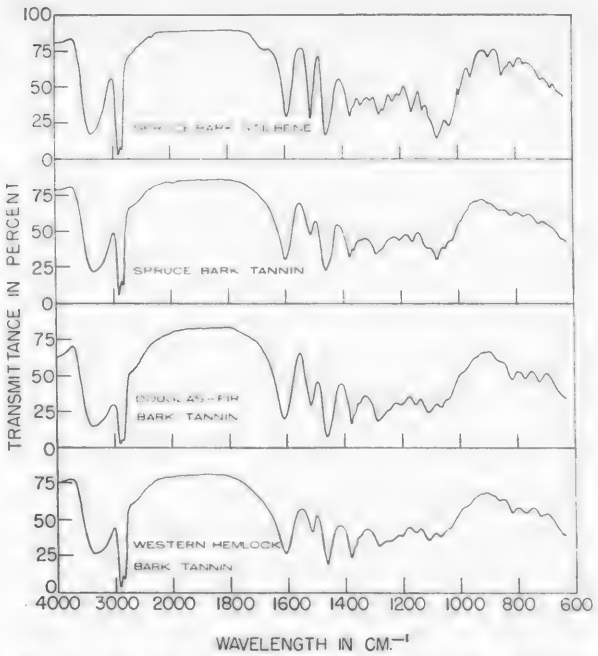



**Fig. 2.—Infrared spectra (paraffin mulls) of A) Stilbene glucoside (IV) from black spruce bark, B) Sitka spruce bark tannin; C) Douglas-fir bark tannin; and D) Western hemlock bark tannin.**

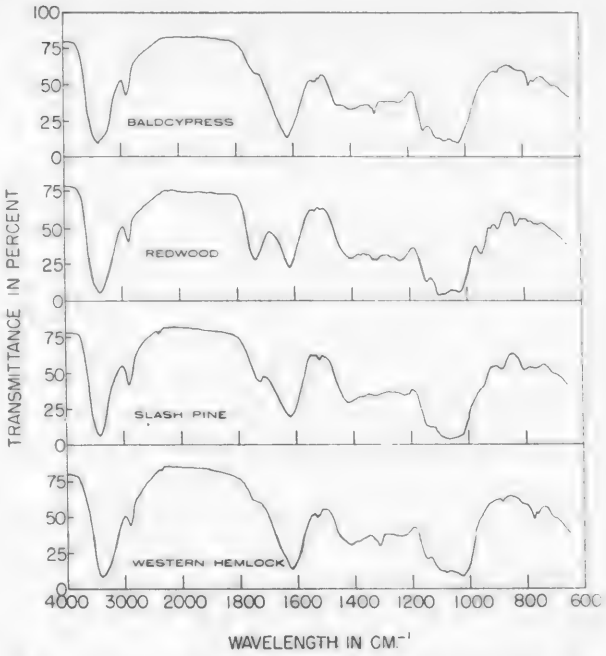



**Fig. 3.—Infrared spectra (potassium bromide wafers) of the water-soluble, methanol-insoluble carbohydrate fractions from A) Bald-cypress bark; B) Redwood bark; C) Slash pine bark; and D) Western hemlock bark.**

## Discussion

**Distribution of Monomeric Polyphenols:** All of the coniferous species examined during this study were found to contain either catechins and monomeric leucocyanidins, the closely-related gallocatechins and leucodelphinidins, or both. These compounds were present in highest concentration in the inner bark adjacent to the cambium and in the cork cambium. A decrease in amount of these compounds centrifugally from the cambium was qualitatively observed by paper chromatography of extracts from successive tangential sections of the bark. A concomitant increase was noted of the polymeric polyphenols (tannins), which have color reactions identical with these compounds but which have low mobility in the solvent systems employed. This observation alone strongly suggests that the polymeric bark tannins are formed from the catechins and leucocyanidins present in a given species. Since these compounds occur in varying ratios, and the configuration of the leuco compounds varies with genera, it may be expected that generic differences in bark tannins should occur.

The sterochemistry and properties of the various isomeric leucocyanidins that occur in coniferous barks also require further study. In this investigation, monomeric leucocyanidins were identified by color reactions, Rf, and conversion to cyanidin. Examination of the structure of leucocyanidin (I) shows that it can exist in four pairs of enantiomorphs, in other words, give rise to four discrete chromatographic spots. The relationship between only one spot and configuration can be assigned with any certainty; however, the other three may be inferred. The leucocyanidin in which the 2,3 hydrogens are *trans* and the 3,4 hydrogens are *cis* is the predominant product of sodium borohydride reduction of dihydroquercetin (1, 13, 14) and is termed leucocyanidin A in Table 2. A small amount of a second leucocyanidin B with slightly different Rf is obtained in this reaction. It is assumed to be 2:3 *trans*, 3:4 *trans*, since sodium borohydride would not be expected to affect the configuration of the 2:3 carbon atoms. The Rf's of the other two pairs, C (2:3 *cis*, 3:4 *cis*) and D (2:3 *cis* and 3:4 *trans*) may then be inferred from the observed chromatographic behavior of catechin (II) (2:3 *trans*) and epicatechin (2:3 *cis*).

While this discussion may seem to be academic with respect to tannin structure or behavior, it is well known that dehydration of *cis* and *trans* alcohols is markedly different. Thus, leucocyanidins (and the corresponding tannins formed from them) with a 3:4 *trans* configuration should be more resistant to dehydration and consequent formation of cyanidin or highly-colored polymers than those polymers derived from 3:4 *cis* leucocyanidins. This may explain why some coniferous tannins, such as Monterey pine, give rise to red leathers more readily than other tannins such as from hemlock. The same configurational arguments apply to leucodelphinidin, except that no attempt has been made in the present study to correlate Rf with configuration. This is due to the much smaller quantities, in general, of leucodelphinidins present in bark and wood as compared with leucocyanidin.

Although monomeric leucocyanidins and catechins are present in the cambium and the sapwood of the species studied, these compounds are absent in the heartwood. In place of these compounds, polymeric leucocyanidins are present in the heartwood. Since extractive-free heartwood of the more highly-colored species, such as Douglas-fir, gives a positive leucocyanidin reaction upon treatment with propanol-HCl, it seems likely that some polymeric leucocyanidins are absorbed on or deposited in the cell wall of the fibers in the heartwood. Those species (Douglas-fir and redwood) with the higher content of leucocyanidins in the sapwood also appeared to have more intensely colored heartwoods than those species (true firs and pine) which have low contents of leucocyanidins in the sapwood. These facts, coupled with the observation that colorless polymeric leucocyanidins present in the inner bark become pink to reddish-brown colored upon exposure to air, suggests the following sequence in heartwood color formation: leucocyanidins and catechins (and other as yet unidentified polyphenols in the case of western red cedar) are directed

centripetally from the cambium. Polymerization takes place upon conversion of the sapwood to the heartwood. Oxidation brings about color formation, the extent of which is determined by the amount of polymeric leucocyanidin present. The polymerization of leucocyanidin, which takes place upon the conversion of the light-colored, living sapwood to colored, dead heartwood, may be chemically analogous to the conversion of the light-colored, living inner bark to the brown, dead outer bark (15). The inner bark, which contains a much higher content of leucocyanidins and related compounds than the sapwood, forms outer bark, which is more intensely colored than the corresponding heartwood.

**Structure of Polymeric Polyphenols:** All of the polymeric polyphenol (tannin) fractions isolated from the species listed in Table 1 gave positive color reactions for the presence of unconjugated phloroglucinol nuclei and catechol groups. Furthermore, acidic hydrolysis produced cyanidin in every case and also delphinidin from cypress, pine, redwood, and larch. Low yields of cyanidin were obtained from hemlock, redwood, and cypress, relatively high yields were obtained from pine and larch. This would seem to suggest that some of the conifer tannins contain a higher proportion of leucocyanidin or leucodelphinidin nuclei than others. Since the amount of cyanidin formation may be related also to configuration, or the same leucocyanidin nuclei may be linked in such a way that they cannot yield cyanidin by acid treatment, it is not yet possible to determine the amount of leucocyanidin nuclei in a given tannin by these tests.

The ultraviolet spectra of the tannins show absorption bands only at 280–282 millimicrons, with an absorptivity slightly larger than catechin or leucocyanidin, and near 200 millimicrons. The only exception to this is spruce tannin (see Fig. 5), which also shows a shoulder at 320 millimicrons due to the presence of stilbenes. The infrared spectra of the tannins, with the exception of that from spruce, were all very similar, but not identical. The absence of absorption bands in the 1625 to 1750 cm.$^{-1}$ region indicated the absence of ketone, aldehyde, carboxyl, or ester groups. The only readily discernible differences in the spectra occur in the 1025–1200 cm.$^{-1}$ region of the spectra, and these differences were not in wave length but in intensity. The absorption bands in this area are assigned to vibrations of aliphatic hydroxyl groups and ether linkages. It is concluded that such spectral differences as occur may be attributed to configuration and varying proportions of catechin or leucocyanidin in the polymers. Comparison of the infrared spectra of these conifer tannins with the spectra of various hardwood tannins determined in this laboratory and elsewhere (16) show distinct differences. This can only be attributed to the presence of different monomeric units in the hardwood tannin than in the conifer tannins.

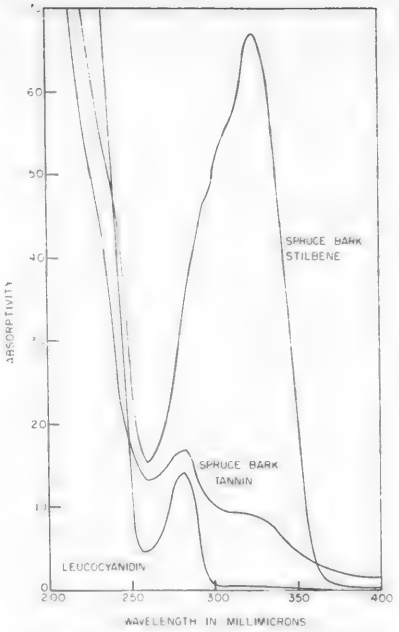



**Fig. 4.—Ultraviolet spectra (in ethanol) of the stilbene glucoside from black spruce bark, sitka spruce polymeric tannin, and leucocyanidin obtained by sodium borohydride reduction of dihydroquercetin.**

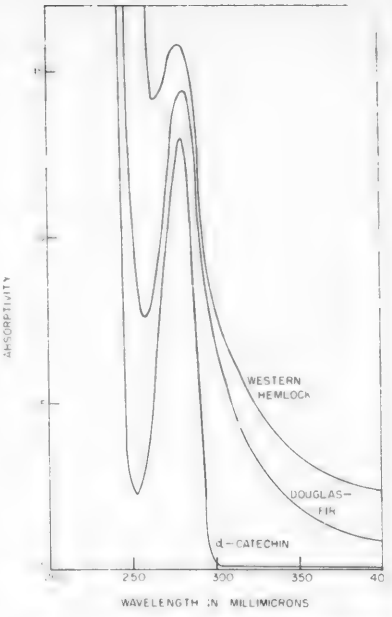



**Fig. 5.—Ultraviolet spectra (in ethanol) of the polymeric tannins from western hemlock bark and Douglas-fir bark and of d-catechin.**

The tannins of several genera included in this report (larch and spruce) have been used commercially, mainly in Europe, and have been studied by other investigators. For this reason, the constituents of several tannin extracts will be discussed in greater detail in the following paragraphs.

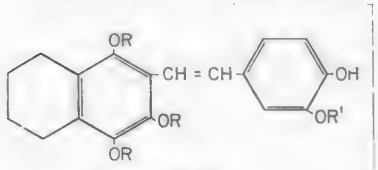
*Larch Tannin:* Aqueous extracts obtainable from the bark of the common European larch *(Larix decidua)* have been used extensively in Europe and, especially, Russia for tanning (16). The only previous report on the chemistry of larch bark tannins is that of Larsen and Lynn (18). They suggest that tannins from American larch *(L. laricina)* bark are of the catechol type. Dihydroquercetin and dihydrokampferol have been found in the heartwood of European larch (19, 20), Japanese larch *(L. leptolepis)* (21, 22, 23), and western larch (24). Dihydroquercetin-3′-glucoside has also been detected in western larch (25).

In addition to these previously-found flavonoids, two-dimensional chromatography of western larch wood and bark shows the presence of catechin, epicatechin, and leucocyanidin. Absent from wood but present in bark are gallocatechin, epigallocatechin, leucodelphinidin, dihydromyricetin and dihydromyricetin glucoside. With respect to the presence of the latter two compounds, larch is similar to pine. It differs from the yellow pines in the absence of the corresponding flavones and the presence of a phenolic stilbene of unknown structure in the inner bark. This stilbene is probably a glycoside, since it has a relatively low Rf in butanol-acetic acid.

Treatment of the polymeric tannins from larch or a commercial larch tannin from Sweden with methanol-HCl resulted in the formation of cyanidin (detected chromatographically). The marked decrease in content of monomeric leucocyanidins and catechin centrifugally from the wood cambium to the outer bark and the concomitant increase in low Rf tannins leaves little doubt that larch tannins are essentially copolymers of leucocyanidin and catechin. In color and solubility, a larch tannin extract closely resembles the extract from Douglas-fir bark.

*Spruce Tannin:* Aqueous extracts of spruce bark have been mainly used for tanning in Germany and, to a lesser extent, in other European countries. An extensive technical literature has appeared (for reviews, see 26, 27), but the composition of the extract had received little investigation until the advent of paper chromatography. Lindstedt and Zacharias (28) demonstrated the presence of at least

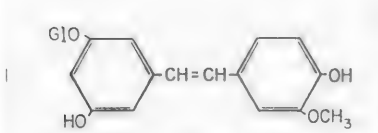
21 compounds in the acetone-soluble fraction from Norway spruce *(Picea abies)*, while Kotosek (29) indicated that 6 ultraviolet-fluorescing compounds and 8 polyphenols were present in aqueous extracts of Norway spruce bark. None of the compounds were identified, however. In subsequent work, Grassman and co-workers (30–33) have shown that the inner bark contains a number of stilbene glucosides. The one occurring in largest amount was separated on a polyamide column and found to have structure III, in which R′ = glucose and R = H, H, and glucose (position not determined). Endres (26) has suggested that at least part of the high-



FORMULA III

molecular-weight tannins or phlobaphenes present in spruce outer bark may be derived from these stilbenes through enzymatic action. Many years ago, Freudenberg (34) considered spruce tannin to be a catechin-tannin. Recently, he stated (35) that spruce bark contains catechin, dihydroquercetin, and a "hydroxy-rich" phenol, but no experimental details were presented.

In studies at the Institute of Paper Chemistry (36), a crude product, which was believed to be a glucoside of a chalcone-like compound, was isolated from black spruce *(Picea mariana)*. From the mode of isolation, it is likely that this product was a mixture, although the properties of the acetate derivative correspond fairly closely to those of the corresponding derivative of a stilbene glucoside isolated by Andrews (37) from the phlobaphene fraction of black spruce *(P. glauca)* bark. Hoffman (38) has suggested that this stilbene has structure IV on the basis of degradation studies.



FORMULA IV

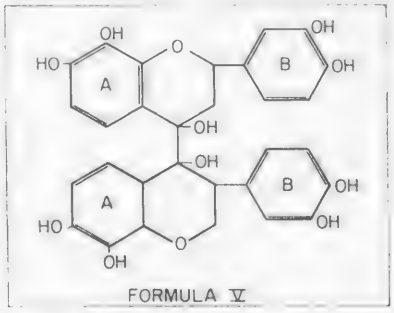
Through the courtesy of Dr. Purves of McGill University, a small sample of IV was obtained. Paper chromatography showed that the product was homogeneous. The chromatographic $R_f$ values and color reactions were the same as those of the principal stilbene constituent occurring in Sitka and Englemann spruce bark. Comparison of the infrared spectrum of this compound (Fig. 2) with that of Grassman's stilbene (27) showed distinct differences, although the ultraviolet spectrum (Fig. 4) was practically identical. In addition to IV and the compounds listed in Table 2, paper chromatograms of Sitka spruce inner bark extracts showed 15 fluorescent spots due to unidentified compounds, presumably stilbenes, and 5 spots due to unidentified, non-fluorescent polyphenols. Many of these compounds are unstable, and apparently polymerize if spruce bark is not immediately extracted upon procurement. They are present in much smaller quantities in spruce outer bark, as are leucocyanidin and catechin, so it appears that the tannin polymers of spruce bark may have a very complex structure. The infrared (Fig. 2) and ultraviolet (Fig. 4) spectra, however, show absorption bands that would be obtained from a mixture of compound IV and a typical polymeric leucocyanidin. Furthermore, treatment of Sitka spruce tannin with propanol-HCl gives cyanidin. This strongly suggests that spruce tannin polymers are derived at least in part from leucocyanidin. Whether the tannin is a copolymer of leucocyanidin, catechin, and stilbenes, or is a mixture of polymeric leucocyanidins, catechins, stilbenes, and so forth, is not evident from the data at hand. Identification of the other monomeric polyphenols in spruce inner bark and extensive degradation studies on the tannin polymer(s) will be necessary before any definite indication of the structure of the polymer can be ascertained.

*Douglas-fir:* Although Douglas-fir bark tannins have had only very limited usage in the tanning industry, large volumes of tannin are potentially available from this source (39). Studies of their isolation (40), elemental analyses, and derivatives (41) have appeared, but no statement as to their probable constitution has appeared. The observation that dihydroquercetin is present in relatively large yields in the bark (41, 42) might suggest a relationship between this compound and the polymeric tannins. The stability of dihydroquercetin (as compared with catechin or leucocyanidin), the absence of carbonyl groups in Douglas-fir tannin (as evidenced by the ultraviolet and infrared spectra), and the distribution of dihydroquercetin (only present in outer bark) strongly suggest that the tannin polymer is not derived from dihydroquercetin. Weinges (43) has recently isolated catechin and epicatechin from Douglas-fir bark. In addition to these two compounds, paper chromatography shows the presence of monomeric leucocyanidins. They are present in large amounts adjacent to the cambium in the inner bark, but are practically absent (in the monomeric form) in outer bark. Color formation, upon treatment with hot butanol-HCl, was used by Hancock (44) as a means of determining the distribution of leucocyanidin in Douglas-fir. No distinction was made between monomeric and polymeric leucocyanidins by this method, but it does provide a rough indication of the total amount present.

Pyrogallol derivatives, such as leucodelphinidin and gallocatechins, and stilbene derivatives are not present in Douglas-fir inner bark. From the study of the distribution of leucocyanidin and the detection of cyanidin as a degradation product, it is concluded that the tannins in Douglas-fir bark are predominantly polymeric leucocyanidins.

*Hemlock:* The aqueous extract of eastern hemlock (*Tsuga canadenis*) was extensively used in North American tanneries in past years (17), but now it has been largely replaced by chestnut extract and imported tannins such as quebracho. Western hemlock tannin, even though it may be obtained in good yield (45), has not been used for commercial tanning. It is used after chemical modification, however, for reducing the viscosity of oil-well drilling muds, and as an intermediate in the manufacture of phenolic resins.

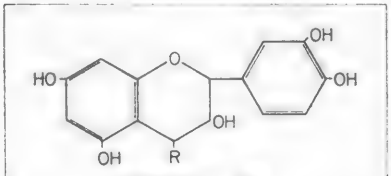
The structure of hemlock tannin was investigated by Russell and Todd (46). They isolated pyrogallol, protocatechuic acid, and catechol in very small yield by alkaline hydrolysis of the tannin from eastern hemlock bark, and claimed that hemlock tannin had the structure of a *bis* (7, 8, 3′, 4′-tetrahydroxy) flavpinacol, V, which they had presumably synthesized.



FORMULA V

Formula V, as a structure for hemlock tannin, is in error for at least three reasons: (a) Hemlock tannin is polymeric. An average molecular weight of about 1730 was obtained by Dr. L. F. Maranville (47) in this laboratory by calculation from diffusion coefficients obtained from a variation of the agar gel method (48). The molecular weight of formula V is 578. (b)

Finch and White (49) have subsequently shown that Russell's synthetic method does not lead to flavpinacols such as V, but to linear tetraphenylhexanediones. The infrared spectrum of hemlock tannin (Fig. 2) shows that hemlock tannin does not contain carbonyl groups, and therefore it cannot be a tetraphenylhexanedione. (c) During this investigation it was found that alkaline fusion of hemlock tannin, according to the method of Roux (50) gives phloroglucinol and protocatechuic acid as the principal degradation products and gallic acid as a minor product. These results suggest a phloroglucinol nucleus for the A-ring, rather than pyrogallol as proposed by Russell, and catechol and pyrogallol for the B-ring. The chromatographic detection of traces of delphinidin, in addition to cyanidin upon acidic hydrolysis of hemlock tannin, indicates the presence of both VI (R = OH) and I monomers in hemlock tannin.



FORMULA VI

The presence of leucoanthocyanins in hemlock wood and bark was previously suggested by Pigman and coworkers (36), but no structural suggestions were put forth. The inner bark of hemlock is particularly rich in monomeric leucocyanidins, but also contains catechin, epicatechin, gallocatechin, epigallocatechin, and leucodelphinidins. It seems likely that these previous investigators were working with a mixture containing all of these compounds. It seems most likely that the polymeric tannins in hemlock are derived from all of these compounds in varying proportions, although the linkages through which they are combined cannot be specified at this time.

*Pine:* Structural studies on yellow pine tannin have been presented previously (1) by the author. It was noted that the polymeric tannins are predominantly derived from leucocyanidin. In addition to leucocyanidin and leucodelphinidin, some of the white pines contain appreciable amounts of substituted stilbenes in the inner bark (see Fig. 1), so the same comments concerning spruce bark tannin may be applicable to white pine tannins.

**Relation of Polyphenols to Pulping:** The inhibition of sulfite pulping by certain heartwood constituents such as pinosylvin is well known. According to one school of thought, delignification is prevented through condensation of reactive phenols and the benzyl alcohol group in lignin during early stages of the sulfite process. If this mechanism is correct, then monomeric polyphenols such as leucocyanidin or the polymeric polyphenols may also be expected to inhibit sulfite pulping. Thus, Douglas-fir heartwood, which contains small amounts of these materials, is somewhat resistant to sulfite pulping, while redwood heartwood, which contains relatively large amounts of polymeric polyphenols, is definitely resistant towards the sulfite process. Conifer bark contains large amounts of polyphenolic compounds, both as extractives and cell-wall components (phenolic acids). It cannot be pulped by the sulfite process at all, even if it is pre-extracted with water or ethanol. The kraft process may be used to pulp bark, however, since the polyphenolic materials are freely soluble in alkali. A large excess of caustic is necessary to make up for the consumption of alkali by these nonlignin components.

**Polyphenols and Taxonomy:** Examination of Table 2 shows that any attempt to distinguish between genera exclusively on the basis of the flavonoids present is likely to be unsuccessful. If substituted stilbenes are included, however, a reasonable degree of differentiation can be made. For example, hemlock, fir, redwood, and baldcypress may be separated from the other genera on the basis of the absence of flavanones in the bark of these four genera. These four genera may then be distinguished on the basis of the amounts and kinds of leucodelphinidins and gallocatechins (high in cypress and redwood, low in hemlock, absent in fir). Yellow pine may be separated from other genera on the basis of its content of myricetin and other flavones in the bark, and pinobanksin and related compounds in the heartwood. The flavonoids of Douglas-fir and cedar *(Cedrus)* are very similar, but Douglas-fir contains much larger quantities of dihydroquercetin and may be distinguished on this basis. Spruce, larch, and some of the white pines may be distinguished from other genera and each other on the basis of the amounts and kinds of substituted stilbenes present in the inner bark. Western red cedar differs in its content of as yet unidentified polyphenols in the wood. Although these compounds in cedar wood contain catechol groups, they appear to be of a lignin nature (51).

## Conclusions

Monomeric leucocyanidins and catechins were found to be of ubiquitous occurrence in the coniferous genera examined during this investigation. The distribution of these compounds and a study of the properties of the water-soluble polyphenolic polymers (tannins) strongly suggests that the coniferous tannins are derived from these monomers. In some genera, such as spruce, substituted stilbenes may also be incorporated into the polymers. These findings provide a sound basis for subsequent study of the structures of the coniferous tannins, and may suggest further uses for these naturally-occurring polymers, which are potentially available in large volume.

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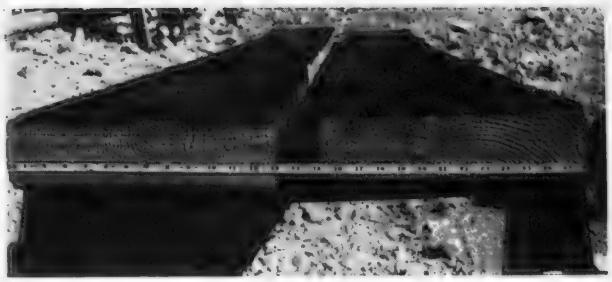
# Wood Outperforms Steel



ALTHOUGH CHARRED, wood members were still structurally sound.

TWISTED STEEL members as a result of exposure to fire.

WOOD CONVINCINGLY OUTPERFORMED unprotected steel during a series of three important fire tests recently held in San Antonio.

The tests, conducted by the Southwest Research Institute, were part of the National Wood Promotion Program data development series designed to provide factual information on the fire performance of wood and unprotected steel in controlled experiments.

Careful attention was given to each phase of the experiments to insure exact equality of testing procedure. Room framing members of both wood and steel were loaded to their design capacities of 30 pounds per square foot by the addition of carefully weighed sand bags uniformly placed along the axis of each room support.

Each room system was constructed independently of the other, so that each was free to deflect under its own load as the test progressed.

Fire was provided by six equally spaced industrial gas burners directed through ports in the walls. The distribution of heat (which reached a maximum of 1400° F.) was uniform and carefully controlled by temperature measuring devices attached to the surfaces of members being tested. Progress of the tests was followed on an instrument panel containing a clock and a roof deflection indicator.

In the first two test 4 x 14 inch wood joists were pitted against 14 inch steel bar joists. In the third test, 9 x 26 glu lam beams were matched against equivalent 9 x 24 inch steel I-beams on 58 foot clear spans.

The results of the first test, which lasted 13 minutes and was conducted privately, showed that the steel joists had deflected beyond further usefulness. The wood members, however, retained 80 percent of their original load capacity.

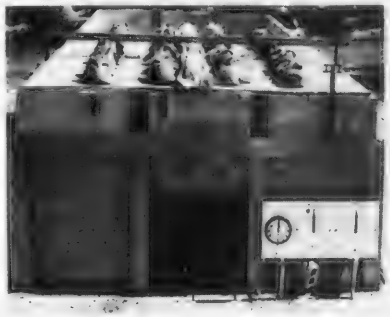
The second test, witnessed by a group of key building officials, insurance rating engineers, and other interested persons, provided a dramatic highlight in the series. After approximately 13 minutes of exposure, the portion of the roof supported by steel joists collapsed entirely into the test chamber below.

The wood members used in this same test, although charred, were still structurally sound and still supporting their section of the roof.

During the third and final test wood continued to make a favorable showing. After 34 minutes of testing, most of the time at temperatures at about 1000° F, the steel had deflected more than 15 inches—enough to endanger the structural adequacy of the building. The wood had deflected only slightly more than 1 inch while retaining 81 percent of its original load capacity.

These tests will have far reaching significance for the wood industry because for the first time identically loaded wood and steel members have been exposed to identical fire conditions in a controlled experiment—the results of which cannot be disputed.

A final report of the completed tests and a dramatic color motion picture film of the tests will soon be available for use in obtaining more favorable recognition of timber construction by building codes, fire insurance agencies, fire marshalls, architects, engineers, and builders.



TEST BUILDING with roof framing and deck in place.

*Reprinted from the National Wood Promotion Program news bulletin September, 1960*

AUSTRALIA EMPHASIZES

# Applied Research in New South Wales

E. B. HUDDLESTON

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**The Division of Wood Technology was founded in 1935 to: 1) discover new or better uses for forest products; 2) to bring such uses to people who could commercialize them; and 3) to assist in the commercial application.**

**Here is a brief history of the Division's formation, growth, and current program of applied research and technical assistance to the forest industries.**

THE MAIN FORESTS OF NEW SOUTH Wales occur in a strip of land from 100 to 150 miles wide stretching along the entire seaboard of the state. The principal timber-consuming market is Sydney, the capital of the state, with a population approaching two million, situated approximately 400 miles north of the Victoria border and 600 miles south of the Queensland border, on the seaboard. More than half of the state's population is centered in Sydney, with the other half distributed through the state in towns of varying size. The main concentration of his latter half of population is along the Great Dividing Range and the strip between it and the seaboard.

## The Forests

Excepting the planted areas, the forests all contain a mixture of species, with the eucalypts predominating. The association varies according to altitude, aspect and location. High-altitude eucalypt forests produce timbers in the lower density ranges (30 to 55 pounds per cubic foot air dry) while the coastal strip carries timbers mainly in the range from 50 to 70 pounds per cubic foot air dry. A few species of lower density may be found in association with these latter. Rain forests occur in pockets within the the eucalypt forests. These are of jungle type and carry a diverse range of species, from those having a density of approximately 18 pounds per cubic foot to others with a density up to 65 pounds per cubic foot.

Hoop pine, a native *Araucaria,* grows in association with the rain forests but because of preferential logging in the latter part of the last century, and the early part of this one, it no longer provides any substantial part of the timber supply. A few other conifiers occur in association with the eucalypt or rain forest, but if marketed, are generally mixed with other species. On the western slopes of the Great Dividing Range and extending onto the Western Plains cypress pine occurs, usually in association with eucalypts and acacias. Further west the tree growth is mainly eucalypt and acacia, but the latter forests produce very little commercial timber. River red gum grows along the western rivers, and contributes to timber supply in the western districts, particularly along the Murray River. Some of it finds its way to the Victoria market where it is much favored for fencing.

## An Import History

In the early days of the Colony, the timbers of N.S.W., with few exceptions, were regarded as being unsuitable for building purposes. They were heavy and hard, failed to float, were difficult to work, and generally were not regarded with favor. Norfolk Island pine, another *Araucaria* sp., was very early brought from Norfolk Island to provide the timber supplies for the new colony. Later, some restricted use was made of the local hardwoods, and certain species such as red cedar (*Cedrela toona*), and hoop pine, were found to give very satisfactory service. The main supplies of timber, however, were obtained from outside the colony, and in the late 19th century substantial imports of timber were made from Europe and other sources. The net result of this lack of regard for the properties of Australian timbers led to selective logging and wasteful utilization of the timber species. In many river flats required to be cleared for agriculture, large tracts of high grade timber were felled and burnt without regard to the potential future value of that timber. Logging, where it did occur, was highly selective and local timber production has never equalled timber consumption, with the result that New South Wales has always been a timber importing state.

## Forestry Act of 1916

At the beginning of the 20th century, forestry was in a perilous condition. The forests had been selectively logged, timber was regarded as of little value, and land was being taken up under Crown Lease and other tenures. A condition of most grants or leases was that a certain amount of

clearing should be undertaken each year. Timber prices were low and main supplies for the state's requirements were being obtained by imports from overseas. In 1916, the Forestry Act was passed by the New South Wales Parliament and the Forestry Commission established. The Commission set about bringing proper forest management to the forest areas of the State.

### Division of Wood Technology

To cope with the difficult problems of extending the utilization of the forest and bringing into use then unused species, the Commission formed the Division of Wood Technology with the stated objective of improving the value of the forest crop. The program of the Division was built on the earlier work of R. T. Baker on New South Wales timbers. A concerted effort was made by the small staff, which included the writer, to provide direct assistance to the timber industry. The group was established at its present location in Sydney, and equipment and facilities set up. Data were accumulated on the mechanical and physical properties, and seasoning characteristics of state timbers.

During the war years, the semi-commercial seasoning facilities were operated continuously and testing facilities expanded. Plywood was developed from rotary and sliced veneers of previously unused species. The staff included a forester who acted full-time as a collector of species for this project. Additional staff was appointed to develop the use of charcoal for motor vehicles. Considerable success was achieved and the project was later transferred to the Department of Motor Transport.

### Current Organizations

Following the war's end, the Division was able to resume the development previously planned. It was hampered, and still is, by inability to recruit and retain suitable staff. At the present time, the staff of the Division of Wood Technology consists of a Chief, Deputy Chief, 21 Research Officers, and 18 Laboratory Assistants, together with the trade and clerical staff necessary. It is organized in seven sections, namely (1) Timber Utilization, (2) Wood Structure, (3) Timber Seasoning and Wood Working Machinery, (4) Timber Mechanics, Timber Physics and Veneer and Glueing, (5) Timber Preservation, (6) Wood Chemistry and (7) Pathology.

### Objective: Applied Research

The major objective of the Division is to discover new or better uses for forest products, to bring such uses before people who may be able to commercialize them, and to assist in the commercial application. Close liaison is maintained with the Division of Forest Products of C.S.I.R.O. by contact with individual officers, and by means of a forest products research conference which is held approximately annually. By arrangement the fields of work of the two organizations have been generally defined: the Division of Wood Technology with applied research in New South Wales. While this general agreement exists, officers of the former division do undertake some applied research and those of the latter some basic research. If an officer's work in the applied field leads him into problems requiring basic research for their solution he has the alternative of requesting an officer of another organization to undertake the work, or of doing it himself. Should the latter be considered the best means of proceeding, overlap and waste of effort is avoided by contact and discussion between those who may be working that field.

The general method of achieving the objective is to determine first the application it is desired to achieve. This is then brought to the notice of people who may be able to apply it commercially either by personal contact, by publicity, or by exhibits. When such a person is found, assistance is provided in solving problems which arise in production or marketing, until the product is well established.

### Industrial Advisory Service

The Division maintains a semi-commercial timber yard where seasoning kilns, a preservation plant, and a sawmill are installed. The yard is stocked with quantities of most species of New South Wales timbers so that samples may be provided to interested persons, and in some cases small supplies of timber provided for trial purposes. Whenever a change in use for a particular species is contemplated, or a new species is being developed for use, stocks in the timber yard are built up to meet the demands of people who may require timber for trial purposes.

When new seasoning kilns or new preservation plants are installed by a member of the timber industry, officers from the Division assist the operator in overcoming initial difficulties. This assistance is available, free of charge, until the plant is placed on a routine basis. Thereafter samples will be analyzed and assistance given but fees are charged for such work. In the field of sawmilling, advice is given on sawmill design and layout, and again officers of the Division assist industry in the installation of their sawmills and in overcoming production problems associated with them.

An advisory service is available to any producer or user of timber. Attempts are made to bring to the notice of as many people as possible new developments in the production and use of timber and other forest products, in the hope that enquiries from these people will lead to new or extended uses of forest products. The Division publishes pamphlets, bulletins, and leaflets and an irregular periodical entitled "Technical Notes". The three first-mentioned series are intended to deal with a range of subjects at different technical levels, whereas "Technical Notes" is intended to bring new developments to the notice of its readers.

### Projects in Progress

*Ad hoc* work for the timber industry occupies much of the time of the research staff, but a number of research projects are in progress. The Chemistry section is studying the chemistry of the cold water extracts from the bark of *Pinus radiata* and at the same time developing their use as an adhesive. Of interest in the Utilization section is a study of clear finishes for exterior use of timber. The Wood Structure section is investigating the structure of bark as an aid to identification, and in conjunction with the Chemistry section, the occurrence of starch in wood.

The Forest Pathology section is working on the use of weedicides and herbicides as an aid to forest operations, and is making use of the analytical techniques for starch developed by the Chemistry section to study the effect of defoliants and disease on trees. Plantation-grown *Pinus radiata* is assuming considerable importance in the state's timber supply and the Timber Mechanics section is currently engaged on a program to determine the mechanical properties of first and second thinnings from the various plantations. The Seasoning section is concerning itself with developing suitable drying schedules for radiata pine products. Problems in the treatment of timber by diffusion of chemicals into the green timber are occupying the attention of the Timber Preservation section. The latter section is also concerned with studies of lyctus spp. and *Anobium* spp. It is also looking at the control of Bostrychid borers in timber being seasoned for pressure treatment, and even in treated timber.

# Abstracting the Literature

## IMPREGNATION

**Karpov, Vladimir L., Malinsky, Yuri M., Serenkov, Vasili I., Klimanova, Raisa S., and Freidin, Anatoli.** Radiation makes better woods and copolymers. Nucleonics 18, no. 3:88–90 (March, 1960).

Wood is impregnated with a suitable monomer such as styrene and subjected to ionizing radiation to effect polymerization of the monomer. The prod. is improved in strength, dimensional stability, and dielec. const.; is provided with a decreased water absorptivity; and is improved in resistance to chemicals, fire, and fungi. Textiles and paper may be trd. in similar fashion, in which case the process might be used for the preservation of museum items and archeological treasures. (A.B.I.P.C. 30:10)

## PARTICLE BOARD

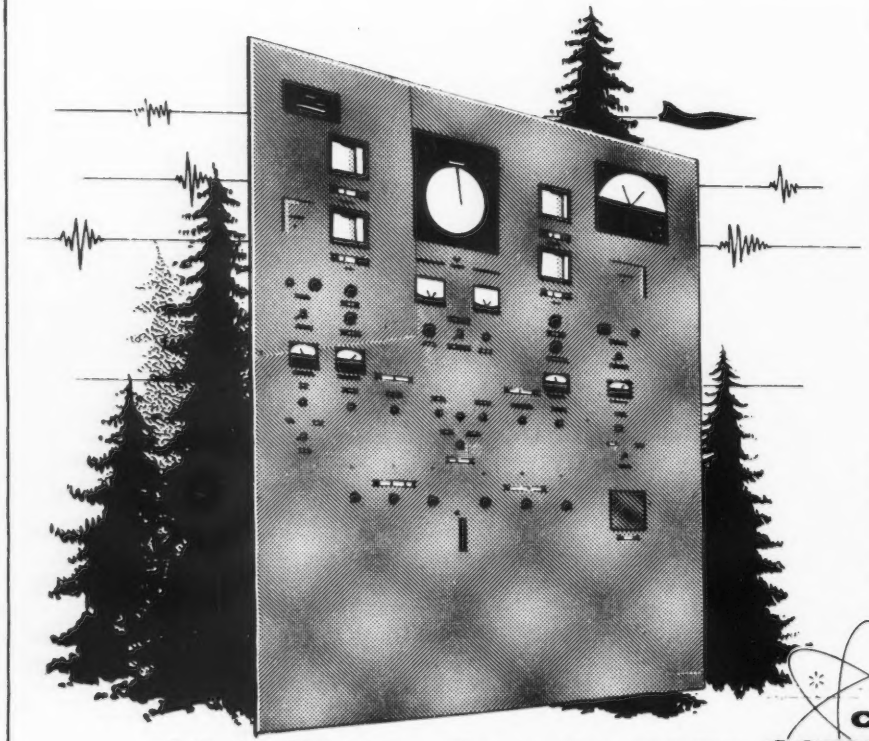
**Liiri, Osmo.** Investigations on the effect of moisture and wax upon the properties of wood-particle board. Paperi ja Puu 42, no. 2: 43–5, 48–50, 52–6 (Feb., 1960). [Finn.; Engl. sum.]

Particle board (*I*), being composed of *ca.* 90% wood, is hygroscopic like wood but, because of its sheet structure, is affected unlike wood by moisture. *I* shows max. strength at 8–9% moisture content, corresponding to 60–65% R.H. at 20°C. At very high R.H., the strength can decrease to one half of the max. During soaking in water, the strength decreases rapidly and considerably, even if *I* contains wax. Wax retards water absorption and swelling of *I* soaked in water, esp. in short-term tests. Because wax is much more effective in controlling the results of soaking tests than of humidification tests, its use in *I* is of questionable value. Wax does not affect the bending strength of *I* but decreases the tensile strength perpendicular to the board surface by 7–8%. The effects of wax addns. are esp. marked in the 0–5% range (based on dry resin wt.). The results of water-soaking tests can vary widely with the procedure used and, for a given method, depend greatly on the size and position of the specimen during soaking. Humidification tests are subject to fewer influences and are, therefore, more suitable than soaking methods for evalg. the hygroscopic props. of *I*. 6 ref. (A.B.I.P.C. 30:10)

## WOOD WASTE

**Allison, F. E., and Cover, R. G.** (U.S. Dept. Agr.) Rates of decomposition of shortleaf pine sawdust in soil at various levels of nitrogen and lime. Soil Sci. 89, no. 4; 194–201 (April, 1960).

Lab. studies are reptd. in which the rate of decpn. of short-leaf pine saw dust in soil was detd., using various kinds and rates of nitrogen in the presence and absence of lime. A convenient system for the detn. of carbon dioxide evolution is described. Under conditions of air satn. with moisture, wood particles that barely passed through a 6-mesh sieve decomposed about as rapidly as did smaller ones; similarly, particles left on the soil surface decomposed about as rapidly as when mixed with the soil. During an incubation period of 72 days at 30°C., the release of carbon dioxide from unlimed sawdust without added nitrogen was 68% as great as with adequate nitrogen; in the presence of 0.4% calcium carbonate the corresponding value was 79%. Nitrogen addns. sufficient to make the nitrogen content of the wood 0.75–1.0% were adequate for a max. rate of decpn. in the low-nitrogen sandy loam used. This value varies with the ability of the soil to supply nitrogen. Sawdust decpn. was favored more by the addn. of nitrate-nitrogen than by ammonium salts, where the devt. of acidity was not controlled. A covariance anal. showed that the inferiority of ammonium was due chiefly to the higher acidity. (A.B.I.P.C. 30:12)

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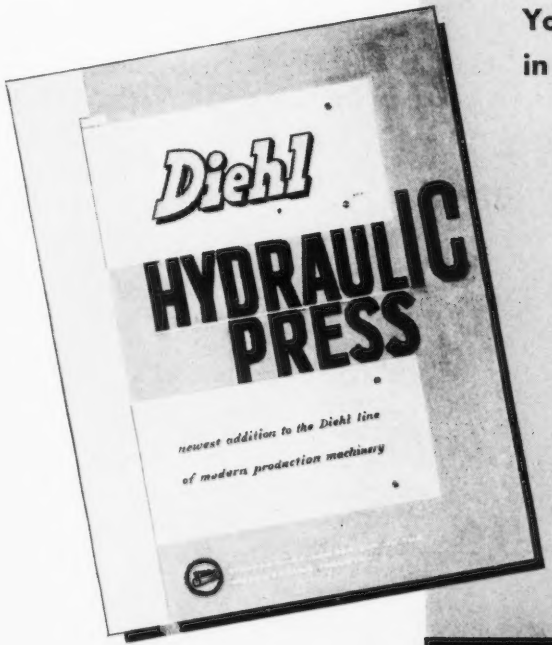


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